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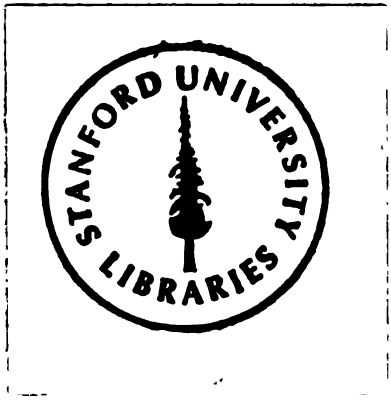

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A. H. Whatley, *Treasurer*

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SUMMARY OF MEMBERSHIP BY RESIDENCE

United States

Alabama	48	Nebraska	10
Alaska	1	Nevada	1
Arizona	10	New Hampshire	20
Arkansas	6	New Jersey	496
California	246	New Mexico	7
Canal Zone	6	New York	2112
Colorado	42	North Carolina	28
Connecticut	426	North Dakota	3
Delaware	69	Ohio	577
District of Columbia	176	Oklahoma	55
Florida	24	Oregon	12
Georgia	49	Pennsylvania	1012
Hawaii	14	Philippine Islands	13
Idaho	4	Porto Rico	6
Illinois	582	Rhode Island	103
Indiana	145	South Carolina	16
Iowa	27	South Dakota	3
Kansas	34	Tennessee	52
Kentucky	22	Texas	60
Louisiana	47	Utah	18
Maine	30	Vermont	29
Maryland	105	Virginia	66
Massachusetts	730	Washington	42
Michigan	296	West Virginia	20
Minnesota	95	Wisconsin	146
Mississippi	9	Wyoming	4
Missouri	147		
Montana	11	Total	8312

Foreign Countries

Africa	11	India	8
Australia	9	Italy	2
Austria	2	Japan	11
Belgium	1	Mexico	6
British West Indies	1	Norway	3
Canada	140	Roumania	1
Central America	1	Russia	8
Channel Islands	1	Scotland	5
China	8	South America	31
Cuba	28	Spain	2
Denmark	2	Sweden	6
Dutch East India	1	Switzerland	3
England	61	Turkey	1
Finland	4	West Indies	2
France	26		
Germany	19	Total	406
Holland	2		

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Membership in United States	8312
Membership in Foreign Countries	406
Present address unknown	2
Total Membership	8720

Membership by Grades

Honorary Members	15
Members	5053
Associates	504
Associate-Members	1191
Juniors	1957
Total Membership December 31, 1917	8720

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TRANSACTIONS

OF

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

VOLUME 39 — 1917

VOLUME 39 of Transactions contains an account of the activities of the Society for 1917, the year in which the United States entered the great war. The volume includes the papers and addresses given at the Spring and Annual Meetings and a selection of papers presented at meetings of the Local Sections. Inevitably many of these relate to problems with which engineers are concerned in the prosecution of the war and to which, with patriotic devotion, they are giving their undivided thought and attention.

At the beginning of the war this Society, in common with many others, tendered its services to the President of the United States. The offer was promptly accepted to the great satisfaction of the membership, and as the needs of the Government have grown the Society has responded to the many requests which have come to it.

Individually, also, the members have heeded the call and are serving in almost every department of the Government, abroad at the front, at the Nation's Capital, in arsenals, navy yards, shipyards, aviation fields, etc., and in the industries of the country engaged in munitions manufacture. The earnest and helpful spirit resulting from these many points of contact is reflected in the pages of this volume.

IRA NELSON HOLLIS

"Brotherhood of all engineers and their united action in any service that will be for the good of our country" — a splendid motto, worthy and characteristic of the new president of The American Society of Mechanical Engineers. With the anticipated coöperation of the presidents of other national societies, engineers may be expected

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to behold their profession in a broader aspect and in a new relation to the world which they serve. And with their characteristic energy they may speedily create for themselves a field of greater usefulness with corresponding prestige and emoluments. To such a prayer all engineers will say Amen!

March 7, 1858, and Mooresville, Ind., among low mountains called the "Knobs," were the time and place of the birth of Ira N. Hollis. New Albany, six miles away, was his home from 1858 to 1868. The family then moved to Louisville, Kentucky. The Hollises, originally English, moved from Berkeley County, Virginia, to Jefferson County, Kentucky, soon after the Revolution. Lewis, Ira N. Hollis's grandfather had nineteen children, all of whom grew up; and Ephraim J., his father, had four, a son and three daughters. The grandfather fought in the battle of Tippecanoe, and the father served four years as an officer in the Civil War, ending in Sherman's march to the sea. His mother, Mary Kerns, also of English origin, moved into Ohio from Pennsylvania. She was the daughter of the contractor who built the Ohio & Mississippi (now Baltimore & Ohio) R. R., west of Seymour, Ind.

Starting in a private school in New Albany, Hollis continued his education in the grammar and high schools of Louisville. In his senior year he won the second of the two gold medals given by the city for high scholarship. Louis D. Brandeis, now a justice of the United States Supreme Court, won the first. Obliged to go to work, he was apprenticed to Webster's machine shop and foundry in New Albany, where river-steamboat engines were built. Health failing after a year, he found lighter employment as a clerk on the transfer platform of the Louisville & Nashville R. R. freight depot in Louisville. Six months later he went to Memphis as bookkeeper in a cotton commission house.

It was in the spring of 1874, when at the age of eighteen, that Hollis saw a way open to complete his education. The four-year course for engineers had just been established at the United States Naval Academy, to which 25 cadets were to be appointed annually on competitive examination. Thomas Scott, president of the Pennsylvania R. R., furnished him a pass to Annapolis and return, and Mr. Keane, manager of the Louisville Hotel, financed him for the trip.

Turned away at the academy for want of credentials, he proceeded to Washington, where, watching his opportunity, he appeared unannounced before the Secretary of the Navy. An hour's talk with

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the secretary sufficed to secure a permit, armed with which Hollis returned to Annapolis and took the examination with 75 others from all sections of the country. This was early in September.

It was a disheartened boy who returned home after his examinations, fearing he had failed miserably. There had been little time to prepare except on the train, and physics had not been included in his high-school course. Imagine his surprise a few days later to receive orders to report at Annapolis on October 1, and his joy on arrival to find that he had passed No. 1.

At Annapolis, Hollis early took the lead, which he maintained and graduated No. 1 in 1878. Not only that, but he found time to pursue advanced courses in several subjects and did considerable reading. In his first-class year he was appointed chief cadet officer of the Engineer Division. His interest in athletics was such that, had his strength permitted, he would gladly have shared scholarship with physical prowess. Desiring to follow naval architecture, he applied for orders to go abroad for study, but the department's policy in this regard was not established until the following year. Then and for many years thereafter the two graduates with highest standing received the coveted honor.

On September 20, 1878, Hollis reported for duty on the *Quinnebaug*, fitting out at the Norfolk Navy Yard. She was to cruise in European waters, if on her trial trip she made 14 knots. Her 10 boilers of the "powder keg" type, built for 80 lb. pressure, were among the first steel boilers in the navy. Her engines, originally low-pressure, had been compounded by bushing one of the cylinders, but the copper piping had for the most part been left unchanged.

In assigning stations among the four watch officers in the Engineer Division the boilers fell to Hollis. That trial trip with its foaming boilers and squirting feed pipes was a nightmare, but the ship went to Europe. She sailed without Hollis, however, who was detained in the naval hospital with typhoid and joined the ship later at Malaga. This cruise lasted 28 months. His next cruise of 19 months was on the *Hartford*, starting in June, 1885. He served on the *Charleston* 26 months, from December, 1889, his last sea service being three months on the *Richmond*.

On returning from Europe, Hollis was ordered, September 2, 1881, to Union College, Schenectady, N. Y., where he served for 34 months as professor of mechanical engineering under the Act of 1879, which authorized the detail of engineer officers of the navy to colleges to teach steam engineering and iron-ship building. His next shore duty

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was with the Navy Advisory Board for nine months, from June 30, 1884, during the building of the White Squadron.

He was on inspection duty for 30 months, from April 15, 1887, in San Francisco, while the *Charleston* was being built at the Union Iron Works. Following his cruise in the *Charleston*, he was ordered to the Bureau of Steam Engineering in August, 1892, where he served for one year. In October he delivered a course of lectures at the Naval War College, Newport, R. I., on Coal Endurance and Machinery of the New Cruisers, later published in the *Journal of the American Society of Naval Engineers* (Vol. IV, No. 14). He resigned, September 30, 1893, to accept the professorship of engineering at Harvard University.

Graduating as a cadet engineer, Hollis was promoted to assistant engineer June 20, 1880, and to passed assistant engineer, at the age of 33, February 19, 1889. It had taken 14½ years to reach the grade of junior lieutenant, a discouraging prospect for young men.

At least twice Hollis may be said to have rendered notable service to the navy. The first was connected with the filibuster *Itata* during the Chilean insurrection in 1891. After her chase by the *Charleston* and surrender in Iquique, a board of survey set a time limit of from six to eight weeks to put her machinery in order to return to San Diego. Hollis, assisted by two other officers and 50 men from the *San Francisco, Baltimore* and *Charleston*, did the work in five days and then brought the *Itata* north without stop at an average speed of 8¾ knots. This accomplishment brought a very complimentary letter from Admiral McCann to the Navy Department. An interesting account of the Chase of the *Itata* was published in the *Journal of the American Society of Naval Engineers* (Vol. IV, p. 360).

But his greatest service to the navy was as a civilian. It had to do with the Personnel Bill, enacted into law March 3, 1899. It ended the line and staff fight of many years' standing. In the early summer of 1879 Professor Hollis, on being asked to contribute to the fund for carrying on the fight in Congress, went to Washington and proposed a plan to Secretary of the Navy Long, which led to the appointment of the Personnel Board, with Colonel Roosevelt, then Assistant Secretary of the Navy, as chairman.

The important features of the plan were: (1) The amalgamation of the line and engineers; (2) the selection of engineers from the line to do engineering duty and to remain as a technical corps; (3) regulation of the flow of promotion; (4) some kind of general staff. There were some thirteen points in all. The subject will be found treated

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quite fully in the *Atlantic Monthly* of September, 1897, and in the *Army and Navy Journal* from August 21 on.

Secretary Long reported favorably to Congress, January 13, 1898; the bill passed the House, January 18, 1899, and the Senate, February 18. Two features advocated by Professor Hollis were omitted: namely, the technical corps and the general staff. But these have since been formed, or are about to be. Notwithstanding his important part in this reorganization work, Professor Hollis would not wish it understood that he did more than help start it and assist when called on in perfecting the bill then being drawn up.

During his twenty years at Harvard, Professor Hollis accomplished many things. An interesting account of them will be found in the *Harvard Magazine* for June, 1913. He took a prominent part in the life of the college and was highly esteemed. The attendance in engineering increased many fold. Largely through his efforts Pierce Hall and its equipment were provided in 1901, and the summer school at Squam Lake, N. H. The Harvard Union and the stadium became realities largely through his efforts. For eight years from the fall of 1895, six as chairman, he served on the Athletic Committee. Sports were moved from Holmes Field to a new site, created out of tide-washed barrens. This became Soldiers' Field, now most completely equipped for every branch of college athletics.

It was while Professor Hollis was on the Athletic Committee that a scholarship requirement was imposed on all who would engage in intercollegiate games. This restriction took practical form in the joint rules between Harvard and Yale, which because of keen rivalry required two years for their enactment.

Professor Hollis's work was largely constructive. Long-established conventions had to be faced, and it was only by his admirable tact that he handled successfully many problems bound about by traditional red tape. His strong character and keen sense of right and wrong have, by long years of discipline tempered by a quick appreciation of humor, made him unusually effective. Those who have been his colleagues and students testify abundantly to his remarkably fruitful life while there.

He was offered and accepted the presidency of Worcester Polytechnic Institute in 1913. Already in his three years at Worcester he has established himself in the affections alike of its governing board, faculty and student body.

President Hollis holds the honorary degrees of A.M., from Harvard, 1899; L.H.D., from Union, 1899; and Sc.D., from Pittsburgh,

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1912. He is a fellow of the American Academy of Arts and Sciences and a member of the American Society of Naval Engineers, American Society of Naval Architects and Marine Engineers, Boston Society of Civil Engineers, and the Society for the Promotion of Engineering Education. He is the author of War College Lectures, 1892; History of the Frigate *Constitution;* and has been a liberal contributor to engineering journals and various other publications.

He was married on August 22, 1894, to Caroline Lorman, of Detroit, a graduate of the University of Michigan. They have four children: Jeanette Ralston, a senior at Bryn Mawr; Oliver Nelson, a senior at Harvard; Elinor Vernon, soon to enter Vassar; and Carolyn. — M. E. Cooley, in *Engineering News*, February 15, 1917.

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ACTIVITIES OF THE SOCIETY FOR 1916–17

IN his address at the business session of the last Annual Meeting, President Hollis presented for the Council a report upon the major activities of the Society during the year of his presidency, which came during the stirring times marked by the first year of this country in the great war. Supplementing this report, the Secretary here presents a summary of the business and committee activities for the year, together with brief reference to a few of the more important events which Dr. Hollis has so thoroughly and ably discussed.[1]

On the retirement of Dr. Jacobus from the presidency in December 1916, the Council recorded a special vote "of sincere appreciation of the untiring, unselfish and earnest service rendered the Society during his presidential year."

Tellers of election announced the ballot for officers for the year 1917 as follows:

President, Ira N. Hollis.
Vice-Presidents, Chas. H. Benjamin, Arthur M. Greene, Jr., Charles T. Plunkett.
Managers, Robert H. Fernald, Wm. B. Gregory, C. R. Weymouth.
Treasurer, Wm. H. Wiley.

"Service to the State" was the keynote of Dr. Hollis' brief remarks in accepting the presidency and foretold the major part of the work of the Society for this year.

Service to the state in these times means service to the Government and the prime consideration throughout the year has been to place the resources of the Society at the disposal of the Government in its conduct of the war.

One of the first and most successful undertakings, to which Dr. Hollis has referred, was that of the Engineering Resources Committee, Mr. George J. Foran, *Chairman*, — that of furnishing specialists for the numerous demands of the Government and the industries generally. Our circular letter to the membership brought in over 6000 replies, all of which have been collated and indexed in the most thorough manner. The Society has furnished names, literally by

[1] See page 547.

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the hundred, in response to requests for experts in varied lines of industry.

A very early undertaking was that of the Military Engineering Committee, formed by the Engineers' Club of New York to arouse engineers to the need for preparedness and to instruct them in military tactics. Our Society, with the three other national societies, participated in the work of the committee. As a result of its efforts 10,000 engineers marched in the great preparedness parade in New York, and a series of lectures on military tactics was given by officers assigned by the War Department. The committee further recruited an entire corps of 1167 men, plus about 160 others, which was sent to France. The expense contributed individually by twenty or more members of the Military Engineering Committee was over five thousand dollars.

This Society also took up energetically at the Spring Meeting in Cincinnati, in May last, the matter of Standardization of Gages, and the officers of the Society went to Washington and discussed the case with the Bureau heads, and we have reason to believe that this helped in passing the regulations providing for the work now being developed in the Bureau of Standards.

Other efforts on behalf of the Government will be mentioned in connection with certain of the committee reports which follow.

We have also a General Engineering Committee of the Council of National Defense, and under the Engineering Council the American Engineering Service Committee and War Committee of Technical Societies.

ENGINEERING COUNCIL

The organization of the latter body was one of the important developments of the year and came as an outgrowth of a real need for proper consideration of questions of general interest to engineers and to the public and to provide means for united action upon questions of common interest. At present the Council is concerned only with the four national societies, but it is hoped that it may become a representative body for all engineers and thus pave the way for a closer and larger union in the future.

At the organization meeting of the Engineering Council, held in the rooms of The American Society of Mechanical Engineers on June 27, the following officers were elected: President, I. N. Hollis; Vice-Presidents, H. W. Buck, George F. Swain; Secretary, Calvert

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Townley. Executive Committee: Those named, with J. Parke Channing and D. S. Jacobus.

The council discussed at length ways and means by which the founder societies through the council might be of use to the nation. The unanimous desire to help the Government in the prosecution of this war resulted in a resolution instructing the executive committee to coöperate with the Government in procuring the services of engineers, also in the appointment of a committee of three, consisting of Messrs. H. W. Buck, A. M. Greene, Jr., and Edmund B. Kirby, to consider the best means of utilizing the inventive ability of members of the founder societies.

Various other committees have been appointed from time to time such as *Finance, Rules, Public Affairs, Fuel Conservation,* and those previously mentioned.

WELCOME TO THE CIVIL ENGINEERS

A source of gratification this year to the members of this Society and to engineers generally throughout the country, was the coming of the American Society of Civil Engineers into the Engineering Societies Building, thus bringing together under one roof the headquarters of the four national engineering societies, representative of the engineering profession of America.

When the gift of $1,500,000 was received from Mr. Carnegie fifteen years ago for the Engineering Societies Building, it was addressed to the four engineering societies and the Engineers' Club jointly; but as the Civil Engineers had their own building ample for their needs at that time, they decided to remain in the headquarters which they then occupied. Mr. Carnegie then readdressed his gift to the other organizations, omitting the Civil Engineers.

The growth of that society, however, ultimately made a change necessary and by vote of its members it decided to join the three other founder societies in the ownership of the Engineering Societies building. Three floors were added to the building, one to accommodate the enlarged library as a result of the addition of the library of the Civil Engineers, and the other two for the headquarters of that society.

In January 1917 the Civil Engineers held their sixty-fourth annual meeting in the Engineering Societies Building, but it was not until the end of the year that their headquarters was sufficiently com-

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pleted to permit removal to their new home, and a meeting of welcome was held on December 7, with addresses by representatives of the American Institute of Mining Engineers, The American Society of Mechanical Engineers and the American Institute of Electrical Engineers. Mr. Charles F. Rand, President of the United Engineering Society, in extending the welcome said that the association of the four national engineering societies was born of a very general desire to secure the full advantages which come from complete cooperation. These advantages had been realized in many previous examples, such as the John Fritz Medal Board of Award, the Engineering Foundation, the backing furnished by the four societies for the International Engineering Congress, and the Joint Committee of Engineering Societies which preceded the Engineering Council.

He said the societies' obligation to Mr. Andrew Carnegie for his gift of over one million dollars used in the construction of the Engineering Societies Building should never be forgotten. He sometimes thought that the signing of a check for that sum may not have been very difficult for Mr. Carnegie, but he was able to certify that the provision of the remaining amount, through the efforts of the Founder Societies and their members, was surrounded by some difficulty, although now fully accomplished. The property of the Founder Societies, including the real estate, the Library and the reserve and endowment funds, exceeding two and one-quarter million dollars, is all free and clear.

He referred to the administration of the United Engineering Society, which occupies the unique position of standing not over but under the Founder Societies, having been formed by them to perform certain specific acts governed by contracts. The Engineering Foundation, which has an endowment fund for research, the Engineering Council and the great Library under the care of the Library Board, are all administered as departments of the United Engineering Society.

STANDING COMMITTEES

The appointments on the Standing Committees for the year 1917 were as follows: *Finance*, W. E. Symons; *Meetings*, A. L. De Leeuw; *Publication*, George J. Foran; *Membership*, W. C. Morris and Nicholas S. Hill; *Library*, A. M. Hunt; *House*, H. O. Pond; *Research*, Albert Kingsbury; *Public Relations*, J. Waldo Smith; *Constitution and By-Laws*, Ira H. Woolson and Jesse M. Smith; *Standardization*, Henry Hess.

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The work and plans of the Standing Committees are given briefly in the following:

FINANCES

The *Finance Committee* reports that the income of the Society for the year ending September 30, 1917, was $207,046.98. The total expenditures chargeable to income were $186,547.57, leaving an excess of income over expenditures of $20,499.41, this being a net balance after reserving $14,000 for obligations undertaken but not yet completed.

The expenditures of the Society per member for the fiscal year just closed are as follows:

General Salaries	$ 2.06
Headquarters, Library, Supplies, etc.	1.84
Committees on Membership and Increase of Membership	1.27
Sections	.98
Council contingencies, mileage and employment	.77
House Committee	.40
Meetings, Annual and Spring	1.18
Year Book	.63
Journal and Condensed Catalogues	8.47
Transactions	2.42
Other activities	2.73
Making a total of	$22.75

The estimated income for the year 1918 is $228,500.

MEETINGS

The *Committee on Meetings* reports that while in the Society's professional work a high standard for papers has been maintained, it has been realized that many members of the Society regard of equal importance the opportunities afforded for personal conferences, special committee meetings and discussion of problems of peculiar interest to a limited number only. This leads to the effort to produce a well-balanced program calculated to stimulate discussions in preference to sessions overburdened with an unduly large number of papers.

The committee has planned during the past few years to have during each Annual and Spring Meeting a so-called "keynote"

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session which should offer an opportunity for the presentation of the broad but timely problems of general interest. With these points in mind, Industrial Valuation was chosen as the general theme for the keynote session of the Annual Meeting, December 1916.

As the Spring Meeting of 1917 came shortly after the declaration of war, the committee felt that the most timely subject was the Manufacture of Munitions. The large attendance at the Cincinnati meeting is in part attributed to the announcement of this important subject and partly to the exceptional opportunity afforded the members of the Society to coöperate with the members of the National Machine Tool Builders' Association, with whom a joint session was arranged.

So important has become the relation of the engineer to the problems resulting from the war that the committee chose for the keynote session of the Annual Meeting, December 4 to 7, 1917, Service of the Engineer to the Public in Times of National Crises.

In connection with the Annual Meeting, December 1916, special memorial exercises were held in honor of John E. Sweet, one of the beloved founders of the Society.

At the Annual Meeting, December 1917, there were special exercises in connection with the conferring of honorary membership upon Major-General George W. Goethals, upon which occasion the address of the evening was delivered by William H. Taft, ex-President of the United States.

At both meetings all the social events were held in the Engineering Societies Building. Owing to this fact the democratic spirit of the Society was more keenly developed, as more freedom was felt on the part of the members and guests in attending these various functions. The spirit of good fellowship thus promoted is a distinct asset to the Society. An account of the Annual Meeting for 1916 was given in Volume 38 of TRANSACTIONS and for 1917 is to be found in the present volume.

The work of the sub-committees of the Committee on Meetings has been exceedingly gratifying, sessions under the auspices of the sub-committees on Gas Power, Machine Shop, Textiles, Railroads and Protection of Industrial Workers having been held during the past year. The Sub-Committee on Gas Power was reorganized with Prof. C. H. Benjamin of Purdue University, as *Chairman*, and a new sub-committee on Foundry Practice, Prof. W. W. Bird of Worcester Polytechnic Institute, *Chairman*, was appointed.

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PUBLICATIONS

The Publication Committee states that THE JOURNAL has been developed by extending the Engineering Survey to include engineering activities outside of those of our own or other societies, especially in the way of engineering research. The Review of Engineering Periodicals has been broadened to include publications in English as well as in the foreign languages. Reviews, written by specialists in their several fields, have been published of notable additions to the literature of our subject. It is the purpose of the committee to make THE JOURNAL an epitome of current information in the field of mechanical engineering. The Council has apportioned to the Publication Committee for the enhancement of the publications of the Society the entire returns from advertising. In fact, without such assistance the standard of excellence could not have been undertaken.

The 38th volume of TRANSACTIONS records the affairs of the Society during the year 1916 and includes the annual report of the Council, giving a résumé of the activities of standing and special committees, and a calendar of the 103 general and local meetings held during this period. It also contains, under 46 titles, all the papers and discussions presented at the Spring Meeting, held in New Orleans in April 1916, and at the Annual Meeting, held in New York in December 1916. A Code of Safety Standards for Cranes, prepared by the Sub-Committee on Protection of Industrial Workers, is presented.

The seventh annual volume of the A.S.M.E. Condensed Catalogues is the largest and most comprehensive edition of this book yet published. The general Mechanical Equipment Directory, which was inaugurated as a distinctive feature in the 1916 volume, appears in this edition in enlarged and improved form. The section of Engineering Data has also been extended and improved in this volume. In addition to the data selected from THE JOURNAL and TRANSACTIONS for the past year, a summary of the work of the standards committees of the Society is included.

The Year Book of the Society, issued in 1917, shows a registration of 7700 members.

REPORTS OF OTHER STANDING COMMITTEES

Membership Committee. Nine meetings of the committee were held during the year 1916–1917, and the number of applications considered in the transaction of its work was 2395. Applications from

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former members desiring reinstatement were also considered, 13 being recommended to the Council for such action. It is with deep sorrow that the death of the Chairman of this committee, L. R. Pomeroy, on May 7, 1917, must be recorded. His work for the Society was most painstaking and thorough.

Library Committee. The Library contained 49,702 volumes and pamphlets on October 1, 1916, and 132,070 on September 30, 1917, this extraordinary increase being due to the absorption by the Library of the United Engineering Society of the library of the American Society of Civil Engineers which occurred in February 1917, and which added 67,242 volumes and pamphlets to the collection. Of the current accessions, 206 were presented through our own Society.

In March, Mr. W. P. Cutter presented his resignation as Librarian, which was accepted. Mr. H. W. Craver, Librarian of the Carnegie Library of Pittsburgh, was elected to fill the vacancy, and assumed the duties of the position on April 1. The title of the position was changed to Director of the Library.

The number of readers during the year was 12,710.

The Library Service Bureau has met the needs of inquirers by preparing bibliographies and translations, and by copying articles. Photostatic copies of articles in engineering periodicals are in constant demand and have been sent even to far-distant Australia, Korea and South Africa.

Plans for the expansion of the Library of the United Engineering Society are being made which will render the library unique not only in the collection of technical books and periodicals but also in the service it will be prepared to render to the members of any branch of the engineering profession. These plans have been made possible by the initial gift of $100,000 from Dr. James Douglas, as the beginning of an endowment fund which it is hoped will reach $1,000,000. One of the first steps in these plans is to place on the library shelves every engineering periodical published in the world, no matter in what language, and the same broad policy will be followed in the acquisition of reference books.

House Committee. It was found advisable to make certain extensive alterations in the working offices of the Society's quarters, with a view to providing more room and far better facilities for lighting, arrangement of desks for employees, intercommunication and acoustic properties. These changes were completed by October 1, 1917.

During the year the Societies received as a gift from Miss Hoadley

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a most excellent oil portrait of the late J. C. Hoadley, former Manager, which has been hung in one of the Society's rooms.

Research Committee. The work of this committee has comprised chiefly the preparation of reports by its sub-committees, certain of which have undertaken experimental investigation in this connection. Progress reports by the sub-committees on Flow Meters, Bearing Metals and Lubrication were received by the Council and ordered printed.

Public Relations Committee. Organization meeting was held in the rooms of the Society, October 11, 1917. Dr. F. H. Newell was appointed *Chairman* and Morris L. Cooke, *Secretary.*

Constitution and By-Laws Committee. This committee, at meetings held during 1917, discussed various proposed amendments and additions to the Constitution and By-Laws of the Society, and subsequently recommended changes to the Council. These amendments were approved by the Council on April 20, were presented at the Spring Meeting in Cincinnati in May, and were presented for discussion and final amendment at the Annual Meeting, December 1917. They were subsequently sent to the voting membership and the final vote of adoption was closed March 4, 1918.

Standardization Committee. The most important activity of this committee has been its work in connection with the creation of an American Engineering Standards Committee. Active in this work were jointly the American Society of Civil Engineers, the American Institute of Mining Engineers, The American Society of Mechanical Engineers, the American Institute of Electrical Engineers and the American Society for Testing Materials. It is expected that with time this committee will coördinate the work of every technical association or society in the United States, whether of an engineering or other nature, and will coöperate with the corresponding organization in other countries. A beginning in this direction has already been made in that the British Engineering Standards Committee has invited this American Engineering Standards Committee to send delegates to London to consider a change in the British standard Whitworth thread to the simpler cross-section of the United States screw thread, and to consider also the question of metric threads.

LOCAL SECTIONS

The total number of sections now is 22, one of which is a State Section having five Branches, and an affiliated local engineering society. This includes new sections which have been established,

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during the past year, at Ontario, Indianapolis, Erie, Baltimore, and the Connecticut Section with Branches at Bridgeport, Hartford, Meriden, New Haven and Waterbury.

At the Annual Meeting in December, 1916 and the 1917 Spring Meeting, delegates were present from most of the local sections (16 out of 20 being represented at the Annual Meeting and 17 at Cincinnati). At the 1917 Annual Meeting, 19 sections were represented.

By special request of the Council, the Sections Committee has been asked to meet in the different parts of the country in order to keep in touch with local conditions, and in October the Committee visited the sections at St. Louis, Milwaukee, Chicago, and Detroit, holding enthusiastic meetings at each place.

A close association between the various local organizations of other societies representing the divisions of engineering practice and our own Sections has resulted in the holding of a large number of joint meetings during the season just closed. The largest of these meetings was that held in November 1916, when the Sections from Boston, New Haven, New York and Worcester and the Providence Engineering Society, affiliated with our Society, met with a number of engineering organizations in a visit to New London, Conn. There were over 1600 present on this occasion. In many of the cities where there are sections there is close coöperation between them and the local engineering organizations and sections of other national societies, to the mutual advantage of all concerned and the strengthening of the position and influence of the profession in the community.

In January 1917 President Hollis visited the sections at Detroit, Chicago, Milwaukee, New Orleans, Birmingham and Atlanta. Dr. Hollis's message to the sections was service of the individual to society. In March he made a second tour which took him as far west as the Minnesota Section, whose headquarters are at Minneapolis, St. Paul. En route he visited the sections at Buffalo, Chicago and Indianapolis, receiving a rousing welcome from all. His spirited address on Service to the Country in This Crisis brought forth enthusiastic responses. He has also spoken before the members of the Sections at Boston, New York, Philadelphia and Worcester, and the Providence Engineering Society.

In April the Secretary supplemented President Hollis's visits by a tour to the Sections at Cincinnati, Chicago and Milwaukee, and to Madison and Oklahoma City. The President's trip to the Coast in October afforded an opportunity for him to address the convention of the Southwestern Engineers Society at El Paso, Texas, and to

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visit the Los Angeles and San Francisco Sections and the members at Seattle and Portland. The visit to the latter cities was noteworthy because it was the initial official visit by a President of the Society to that section of the country.

The members of the Local Sections Committee are: D. Robert Yarnall, *Chairman*, Louis C. Marburg, Prof. Walter Rautenstrauch, Dean Charles Russ Richards and Henry B. Sargent.

STANDARDIZATION

Steel Roller Chains. Following committee appointed: C. H. Benjamin, *Chairman;* G. M. Bartlett, Secretary; F. V. Hetzel, E. H. Ahara, J. R. Cautley, J. J. Flather and C. E. Whitney.

Feedwater Heaters. Following committee appointed: V. J. Azbe, B. L. Baldwin, T. J. Cookson, G. F. Gebhardt, J. J. Hoppes, F. E. Idell.

American Engineering Standards Committee. This committee is a standardization committee of the national engineering societies to coöperate by representation on a proposed Joint Committee composed of three representatives each from the national engineering societies, to consider and report back to their respective societies suggested means of bringing about coöperation in the formulation of American engineering standards. Our appointees are: Henry Hess and W. F. Kiesel, Jr.

Gage Committee. In coöperation with the Society of Automotive Engineers and the United States Navy, the following committee was appointed: H. E. Harris, *Chairman*, John H. Barr, Wm. A. Viall and Dr. L. A. Fischer of the Bureau of Standards — acting as Secretary. The purpose of this committee is to develop a central bureau for the certification of gages and to provide adequate facilities for certifying gages used throughout the United States in the manufacture and inspection of munitions of war.

A Public Hearing was held by the Joint Committee at the Annual Meeting of 1917 at which were present representatives of important Government Departments, both Army and Navy, the British Ministry of Munitions of War in the United States, the Canadian Munitions Board and leading munitions manufacturers and makers of gages. The hearing was called for the purpose of considering in a broad, patriotic way, what could be done to accelerate the manufacture of munitions and to provide means by which all munitions, wherever manufactured should be interchangeable.

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Power Test Committee. A public meeting of the Power Test Committee was held during the Annual Meeting of 1917, the object of which was to discuss the various testing codes as published by the Society and to aid the Power Test Committee in such revisions as might be needed to make the codes of the greatest service to the profession, and to bring them up to date.

The members of the Power Test Committee, originally numbering eight, were later increased to twelve (George H. Barrus, *Chairman*), and an Advisory Board, appointed consisting of 15 members of the Society, who are identified with manufacturers and users of power-plant apparatus, whose duties are to attend the public hearings of this committee and to confer with the main committee whenever so requested.

A sub-committee on Water Wheels, to assist in framing a code, was appointed, with delegates from the American Society of Civil Engineers, the American Institute of Electrical Engineers and the Committee on Prime Movers of the National Electric Light Association.

Committee on Limits and Tolerances in Screw Thread Fits. The investigations of this committee, which have been in process for a number of years, are now drawing to a close. The first draft of its report has been completed and reflects much credit on the committee for its painstaking care and tireless efforts. It will be of interest at this time, therefore, to give a résumé of the work of the committee as prepared by its chairman, Luther D. Burlingame:

"During the years following the appointment of this committee, many meetings have been held, and work has been done through sub-committees, involving a great amount of investigation and study.

"A request sent to many tap makers for confidential information showing the limits allowed for their commercial work, led to a response by a number of leading manufacturers, giving such information. This was tabulated and compared. Later, some of the tap makers assisted by having over 4000 taps of standard sizes from $\frac{1}{4}$ in. to 2 in. secured from a number of different makers and measured for errors in lead, in order to obtain the average variation of commercial taps which are in use to-day.

"Early in the investigation, a meeting of screw manufacturers and users was called at Society headquarters, at which about forty representatives were present, and the matter of tolerances and limits in screws was thoroughly discussed in the light of a tentative report which this committee had prepared. This meeting resulted in the

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appointment of a sub-committee to assist by obtaining data from screw manufacturers.

"Through this sub-committee, and the officers of the A.S.M.E., over 5000 screws were obtained from the regular commercial stock of many different manufacturers, representative of various grades and sizes and with cut and rolled threads. These screws were measured and the results tabulated.

"Sample screws and nuts were prepared having varying degrees of error in diameter and lead, and from these it was determined what would be the maximum error allowable, and charts were made to show the relation of taps and screws measured to these allowable limits.

"Sample gages were also made to a closer limit than those now proposed by the committee in order to learn how accurate it was practicable to make commercial work. These gages were distributed without stating what the allowance was in order that the users might not be prejudiced by thinking the limits were closer than they could work to.

Comparisons were also made with the allowances and tolerances recommended by the British Engineering Standards Committee.

"A number of designs of thread gages for various purposes were submitted to 40 prominent manufacturers and users, and their recommendations were taken under consideration.

"While it is believed that eventually three grades should be established, to be called "Commercial," "Machine," and "Precision" grades, suitable for work requiring different degrees of accuracy, "Machine" grade only, from $\frac{1}{4}$ in. to 2 in. diameter, adapted for general work, is tabulated in the present report."

BOILER CODE

The first public hearing of the Boiler Code Committee, under the direction of its chairman, John A. Stevens, was held during the Annual Meeting of 1916 and was largely attended by representatives of the industries.

An Executive Committee of the Boiler Committee was appointed in January to consider questions of revision, and also to render assistance to the Secretary of the Committee under emergency conditions. This Committee consists of the following: D. S. Jacobus, *Chairman*, Wm. H. Boehm, Chas. E. Gorton, S. F. Jeter, W. F. Kiesel, Jr., John A. Stevens, and C. W. Obert. The publication of the interpretations

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in THE JOURNAL has been continued as soon as approved by the Council.

In December 1916 the American Uniform Boiler Code Congress was held in Washington, D. C., under the auspices of the Industrial Commission of the State of Ohio, and the American Uniform Boiler-Law Society. This was a gathering of representatives of the various states interested in a uniform boiler code, which had been called by the Industrial Commission of the State of Ohio, and which proved an important factor in the movement for promulgation of the Code throughout the United States. The Congress was attended by many influential members of the Society who spoke on the subject of standardization and uniformity, and also by others who are prominent in the boiler-manufacturing and legislative fields.

At the end of the fiscal year, 1917, the A.S.M.E. Boiler Code is found to be operative in nine states and eight cities as follows:

New York	Chicago
Pennsylvania	Erie, Pa.
New Jersey	Kansas City
Ohio	Scranton, Pa.
Indiana	Detroit
Michigan	Philadelphia
Wisconsin	St. Joseph, Mo.
Minnesota	St. Louis, Mo.
California	

It is, moreover, used even in the Republic of Argentine, the Republic of Paraguay, and New Zealand. Also the Government specifies boilers in use at the Canal Zone and according to Specification No. 2362 for power-plant equipment at the Naval Training Station, Newport, R. I., boilers and accessories used by this department are to be constructed to the A.S.M.E. Boiler Code. In addition great interest is being taken in the adoption of the Code in a number of other localities, including the states of:

Washington	Rhode Island
Oregon	New Hampshire
Texas	South Dakota
Tennessee	Iowa
Kansas	Utah

and several of the provinces of Canada.

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SPECIAL AND ANNUAL COMMITTEES

Engineering Resources. Following appointments: George J. Foran, *Chairman,* C. M. Allen, John H. Barr, A. D. Blake, and H. C. Meyer, Jr.

Increase of Membership Committee. Effective work has been done by this committee in coöperating with the general Membership Committee in keeping the grade of the membership up to the highest mark.

The Increase of Membership Committee has been reorganized and is now composed of: A. L. Williston, *Chairman;* R. M. Dixon, *Chairman Finance Committee.*

Chairmen of Sub-Committees on Increase of Membership:

Albany — L. C. Brooks
Atlanta — Park A. Dallis
Birmingham — C. B. Davis
Boston — A. L. Williston
Buffalo — W. H. Carrier
Chicago — Philip N. Engel
Cincinnati — John T. Faig
Cleveland — Arthur G. McKee
Detroit — S. J. Hoexter
Erie — H. S. Noble
Indianapolis — L. G. Long
Los Angeles — H. E. Brett
Michigan — H. H. Esselstyn
Milwaukee — Fred. H. Dorner
Minnesota — Max Toltz
New Haven — E. H. Lockwood
New Orleans — A. M. Lockett
New York — J. A. Kinkead
Ontario — C. R. Burt
Philadelphia — T. C. McBride
Pittsburgh — R. Hodgkinson
Rochester — Lucien Buck
St. Louis — John Hunter
San Francisco — C. T. Hutchinson
Schenectady — L. C. Brooks
Seattle — Robert M. Dyer
Tennessee — E. C. Patterson
Troy — L. C. Brooks
Worcester — E. H. Reed

The Committee has been doing most effective work in coöperating with the general Membership Committee in keeping the grade of the membership up to the highest mark.

Nominating Committee, consisting of L. E. Strothman, Willis H. Carrier, Frederick W. Gay, A. M. Lockett and Paul B. Morgan reported that after considering the communications from the membership and as a result of several meetings of the committee and conferences with the Sections, the following were selected:

For President, for one year:
Charles T. Main, Boston, Mass.

For Vice-presidents, for two years:
Spencer Miller, New York, N. Y.
Max Toltz, St. Paul, Minn.
John Hunter, St. Louis, Mo.

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For Managers, for three years:
FRED A. GEIER, Cincinnati, O.
D. ROBERT YARNALL, Philadelphia, Pa.
FRED N. BUSHNELL, Boston, Mass.

For Treasurer:
WILLIAM H. WILEY, New York, N. Y.

Committee on Am.Soc.M.E. Junior Prizes. No award of the Junior Prize was made this year.

STUDENT BRANCHES

That the spirit of coöperation existing in the engineering profession is extending to our coming engineers, is reflected in the forty-five Student Branches. On March 24 a joint meeting of the Branches at Leland Stanford University and the University of California was held at the latter university.

In the East a joint meeting was held in the Engineering Societies Building, in which the students of Branches of the following colleges participated: Columbia University; New York University; The Pennsylvania State College; Polytechnic Institute of Brooklyn; Rensselaer Polytechnic Institute; Stevens Institute of Technology; and Syracuse University.

New Student Branches have been established at Johns Hopkins University, University of Pittsburgh, University of Washington (Seattle), University of Oklahoma and Oregon Agricultural College.

During the year 1916–1917 there were held 212 meetings of Student Branches and in addition conferences of Student Branch representatives at the Annual Meetings both of 1916 and 1917.

Committee on Am.Soc.M.E. Student Prizes. Student prize awarded to Messrs. H. R. Hammond and C. W. Holmberg for their paper on Study of Surface Resistance with Glass as the Transmission Medium.

REPRESENTATION

Trustees of United Engineering Society. E. G. Spilsbury was elected to the Board of Trustees of the United Engineering Society for this year. The representatives now on the Board are: John R. Freeman, I. E. Moultrop and E. G. Spilsbury.

Engineering Foundation. Dr. W. F. M. Goss and E. G. Spilsbury are the Society's representatives on the Board of the Engineering Foundation.

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John Fritz Medal. John R. Freeman on the expiration of a four years' term was reappointed on the John Fritz Medal Board. The representatives of the Society are: Ambrose Swasey, John A. Brashear, Frederick R. Hutton and John R. Freeman.

The John Fritz Medal was awarded to Dr. Henry Marion Howe, in January for "investigations in metallography of iron and steel," and was presented to him in the auditorium of the Engineering Societies Building, New York, on the evening of Thursday, May 10, 1917.

Engineering Council. The following appointments were made on the Engineering Council: Charles Whiting Baker, John H. Barr, Arthur M. Greene, Jr., Ira N. Hollis, D. S. Jacobus.

National Security League. F. H. Clark, C. C. Thomas and Major William H. Wiley were the Society's delegates at the Congress of Constructive Patriotism held at Washington, July 25–26–27.

North Carolina College of Agriculture and Mechanic Arts. Professor Satterfield was the Society's representative at the inauguration of Professor Ruddick as president of the North Carolina College of Agriculture and Mechanic Arts.

American Institute of Architects. In response to an invitation of the American Institute of Architects to a conference with its Committee on Quantity System, Prof. J. W. Roe was appointed special representative for the first conference.

Rivers and Harbors Congress. Genl. Wm. H. Bixby was appointed to represent the Society at the convention of the Rivers and Harbors Congress, December 5, 6 and 7, 1917.

Catskill Aqueduct Celebration. The United Engineering Societies' Committee, consisting of Samuel Sheldon, *Chairman;* Charles Warren Hunt, Calvin W. Rice and E. Gybbon Spilsbury, in coöperation with the sub-committee of the Mayor's Catskill Aqueduct Celebration Committee, on Art, Scientific and Historical Exhibitions participated in the arrangements for the commemoration of the completion of the Catskill Aqueduct. The celebration commenced on October 12, 1917, with appropriate exercises, such as turning on the Catskill water at new fountains in City Hall and Central Parks; emptying the lower Croton reservoir, now to be abandoned; civic parade; exercises in the public schools and exhibitions by the historical, scientific and art societies.

Under the auspices of the United Engineering Societies Committee and the Sub-Committee on Art, Scientific and Historical Exhibitions, an Aqueduct Celebration by engineers was held in the Engineering

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Societies Building, New York, with addresses by Hon. John Purroy Mitchel and Major-General George W. Goethals, and an illustrated lecture on the Catskill Aqueduct by A. D. Flinn, deputy chief engineer of the Metropolitan Board of Water Supply.

Engineering Coöperation Conference. Paul P. Bird, H. C. Gardner and Calvin W. Rice were appointed representatives to the conference on Engineering Coöperation held in Chicago, March 28 and 29, 1917.

Military Engineering Committee. The Committee on Officers Engineer Reserve Corps of this Society, which is part of a joint committee embracing other engineering societies, was requested to continue and to act with the other engineering societies and the United States Government so that there will be one central committee of the engineering profession which shall assist the government, and that the committee has power to select a suitable name, also to add to its membership.

National Research Council — Engineering Committee. In response to the invitation of the National Research Council, W. F. Durand and Chas. D. Young were nominated as representatives of this Society on the Engineering Committee of the National Research Council.

Anglo-American Conference. Invitation from Aircraft Production Board to the London conference. James Hartness was appointed representative.

Coal Conservation. Request from the Fuel Administrator for cooperation in the matter of coal conservation resulted in following appointments: as consulting engineers to the Bureau of Mines, Charles L. Edgar, L. P. Breckenridge, R. H. Fernald, Carl Schultz, Charles Russ Richards; for the U. S. Chamber of Commerce Fuel Committee, the request being made that Dr. Ira N. Hollis, President, serve as one of the members, the President appointed in addition, J. W. Lieb, L. P. Breckenridge and F. H. Clark.

Bureau of Mines. The Society's Standing Committee on Research has been appointed a Special Advisory Committee of the U. S. Bureau of Mines, and the following sub-committees have also been appointed to coöperate with the Bureau: Sub-Committee on Mining Equipment; Sub-Committee on Fuels.

Commission on Gunmounts. Representatives of this Society on commission to determine style on gunmounts for the U. S. Army are Dr. Ira N. Hollis and Dr. D. S. Jacobus.

Washington Award, Western Society of Engineers. The Council received a request from the Western Society of Engineers through its

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Past-President, W. B. Jackson, member of the Council of the Society, to appoint two representatives on the Washington Award Board. This award is to be annually presented to the engineer whose work has been most noteworthy for promoting the public welfare. The President appointed Charles Whiting Baker and M. E. Cooley as the Society's representatives.

SIR WILLIAM H. WHITE MEMORIAL

Shortly after the death of Sir William H. White, on February 27, 1913, a movement was initiated to establish a suitable memorial in his honor, which resulted in subscriptions amounting to over $16,000. A considerable number of the members of the A.S.M.E. responded to the invitation to subscribe to this fund and a goodly sum was sent to the committee in England in the name of our Society, of which Sir William was an Honorary Member.

The memorial has taken three forms:

(1) The "Sir William White Research Scholarship in Naval Architecture," which is to be administered by the Council of the Institution of Naval Architects with a fund of nearly $14,000.
(2) A donation to Westminster Hospital of $500.
(3) A portrait panel in marble of Sir William erected in the Entrance Hall of the Institution of Civil Engineers in London, in which about $1500 is invested.

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MEETINGS JANUARY—JUNE

MEETINGS OF SECTIONS

DURING the first six months of the year seventy-nine meetings were held by the twenty organized Sections of the Society, the Providence Engineering Society, an affiliated body, and the A.S.M.E. members residing in Meriden, Conn., or thirteen more than in the corresponding period in 1916. Eighteen of these meetings were gatherings in which Sections in nine cities coöperated with local technical organizations or branches of other national engineering societies. Twelve Sections were visited and addressed by Dr. Hollis, President of the Society. Among the more noteworthy events were the two-day meetings held by the Minnesota and Boston Sections, the first including a banquet and reception to Dr. Hollis and a symposium on steam locomotives, and the second dealing with extraordinary thoroughness with important problems in power generation in its three technical sessions. A number of the papers of more general interest which were presented at these meetings were published in THE JOURNAL during 1917.

BUFFALO, JANUARY 3

First convivial night of the Buffalo Engineering Society, in which mechanical, electrical, civil, motor-car and other engineers participated.

DETROIT, JANUARY 3

Address by President Ira N. Hollis, on The Scope, Purpose and Opportunities of the Local Section. Other addresses were given by Theodore A. Leisen, A. A. Meyer, Horace Lane, Clarence W. Hubbell and Walter S. Russel.

CHICAGO, JANUARY 5

Dr. Ira N. Hollis, President, Am.Soc.M.E., addressed the meeting on The Status of the Engineer and His Relation to Society.

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MILWAUKEE, JANUARY 9

Subject: The Place of the Engineer and the Engineering Society in Modern Life, Dr. Ira N. Hollis, President, Am.Soc.M.E.

NEW YORK, JANUARY 9

Subject: Industrial Preparedness in Its Relation to Navy Yard Administration, Commander E. P. Jessop, U.S.N.

ATLANTA, JANUARY 17

Address: The Place of the Engineer and the Engineering Society in Modern Life, Dr. Ira N. Hollis, President, Am.Soc.M.E.

BUFFALO, JANUARY 17

Illustrated Address: Highway Bridges, Charles M. Spofford; followed by Frank D. Jackson, who gave some of his experiences with bridges.

CINCINNATI, JANUARY 18

Joint meeting with the Engineers' Club of Cincinnati. Paper: Modern Internal-Combustion-Engine Ignition, J. H. Hunt.

CHICAGO, JANUARY 19

Illustrated Lecture: Problems in Waste Disposal, Henry A. Allen. Abstract published in THE JOURNAL, August 1917.

INDIANAPOLIS, JANUARY 19

Joint meeting with the Indianapolis Engineering Society and the Indianapolis-Lafayette section of the American Institute of Electrical Engineers. Subject: Flow Values through a Manufacturing Plant, Harrington Emerson.

NEW ORLEANS, JANUARY 22

Joint meeting with the Louisiana Association of Members of the American Society of Civil Engineers. Subject: Oil Burning, B. S. Nelson. Published in THE JOURNAL, June 1917.

BIRMINGHAM, JANUARY 24

Illustrated Lecture: The Locomotive Firebox and Combustion Chamber, J. T. Anthony. Abstract published in THE JOURNAL, September 1917.

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LOS ANGELES, JANUARY 24

Subject: How Cities in the United States are Disposing of Their Sewage. Speakers: T. D. Allin and R. V. Orbison.

PROVIDENCE, JANUARY 24

Subject: Some Mechanical Analogies in Electricity, Prof. William S. Franklin.

MINNESOTA, JANUARY 25

Joint meeting with the American Institute of Electrical Engineers, held at the University of Minnesota. Discussion by Charles L. Pillsbury on What is Valuation? followed by E. H. Smith, who spoke on Oxy-Acetylene Welding and Cutting.

BUFFALO, JANUARY 31

Subject: Metallic Alloys, with Particular Reference to Brass and Steel, William M. Corse. Abstract published in THE JOURNAL, April 1917.

ST. LOUIS, JANUARY 31

Joint meeting with the Associated Engineering Societies. Paper: Cotton-Mill Design, George R. Wadleigh.

PHILADELPHIA, FEBRUARY 1

Joint meeting with The Franklin Institute. Paper: By-Product Coke and Coking Operations, C. J. Ramsburg and F. W. Sperr, Jr. Published in this volume.

ATLANTA, FEBRUARY 5 AND 6

Devoted to the entertainment of Prof. L. P. Breckenridge. At a luncheon tendered to him, Professor Breckenridge spoke of the advantages of the different Sections.

BOSTON, FEBRUARY 7

Annual banquet, jointly with the American Institute of Electrical Engineers and the Boston Society of Civil Engineers. Addresses by Dr. Ira N. Hollis, President, Am.Soc.M.E., Prof. Elihu Thomson, Dr. Hugh Cabot, Richard A. Hale, and E. W. Ewartz.

PROVIDENCE, FEBRUARY 7

Subject: Structural Engineering. Discussion opened by Thomas H. Coe.

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BIRMINGHAM, FEBRUARY 8

Subject: Illumination, Prof. A. A. Wittig.

BALTIMORE, FEBRUARY 9

Illustrated Address: The Flow of Values through an Industrial Plant, Harrington Emerson.

PROVIDENCE, FEBRUARY 9

Address: Organization of Industrial and Technical Education Section, Frederick W. Putnam.

ST. LOUIS, FEBRUARY 10

Illustrated lecture by Louis C. Nordmeyer, on China, outlining his experiences while engaged in important engineering work in Shanghai.

ERIE, FEBRUARY 13

Meeting of the Engineers' Society of Northwestern Pennsylvania, to which the Section was invited. Resolution passed to affiliate with the Erie Section.

NEW YORK, FEBRUARY 13

Address: The Engineer and Organization, Dr. Ira N. Hollis, President, Am.Soc.M.E., followed by a paper on Narrow-Gage Motor Cars, by C. W. Hunt.

PROVIDENCE, FEBRUARY 13

Subject: The Units of Measurement in Relation to the Metric System, Luther D. Burlingame.

ST. LOUIS, FEBRUARY 14

Joint meeting of the Associated Engineering Societies of St. Louis with the American Society of Engineering Contractors. Address: The Workmen's Compensation Law, Alroy S. Phillips.

BUFFALO, FEBRUARY 15

Illustrated Address: The Design of the Latest Development of Milling Cutter, Henry A. Brown.

CINCINNATI, FEBRUARY 15

Joint meeting with the Engineers' Club of Cincinnati. Papers: Combined Stresses, A. Lewis Jenkins, published in THE JOURNAL, August 1917; The Doble Steam Car, Abner Doble, published in THE JOURNAL, April 1917.

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BUFFALO, FEBRUARY 28

Lecture: Pure Science Applied to Engineering, Charles F. Kettering.

PROVIDENCE, FEBRUARY 28

Illustrated Address: Edison, His Life and Achievements, M. R. Hutchison.

BUFFALO, MARCH 7

Address by Dr. Ira N. Hollis, President, Am.Soc.M.E., on Services to Our Country in This Crisis. Other addresses by John Younger, William Elmer, Major Frank S. Sidway, A. Conger Goodyear, Evan Hollister, Charles M. Manly, and Herbert A. Meldrum.

ST. LOUIS, MARCH 7

Subject: The Design of Diesel Engines, H. R. Setz.

ATLANTA, MARCH 8

Election of Officers: Oscar Elsas, Chairman; Cecil P. Poole, Secretary; Robert Gregg, J. N. C. Nesbit and Earl F. Scott.

BOSTON, MARCH 8

Joint meeting with the American Institute of Electrical Engineers. Paper: Electric Transmission for Motor Cars, W. B. Potter. Illustrated.

MERIDEN, MARCH 9

Paper: Isolated Power Plant, Charles N. Flagg, Jr.

MINNESOTA, MARCH 9 AND 10

March 9: Banquet and entertainment tendered to Dr. Ira N. Hollis, President, Am.Soc.M.E. Addresses by Dr. Hollis, Dr. G. E. Vincent, and Dr. Marion L. Burton.

March 10: Symposium on Steam Locomotives, held at the University of Minnesota. Papers: Historical Development of the Locomotive, J. V. Martenis; The Locomotive of Today, Max Toltz; Modern Locomotive Practice, T. A. Foque; Superheater Development in America, Geo. L. Bourne; Use of Pulverized Fuel on Locomotives, John E. Muhlfeld; Economy of the Locomotive Superheater, R. M. Ostermann; Locomotive Feedwater Heating, George M. Basford; Metal Alloys Used in Locomotives, G. L. Hoyt. Abstracts published in THE JOURNAL, September 1917.

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INDIANAPOLIS, MARCH 12

Joint meeting with the Engineers' Club of Indianapolis. Address by Dr. Ira N. Hollis, President, Am.Soc.M.E., on the Relation of the Engineer in Civil Life to the Present National Crisis.

BALTIMORE, MARCH 13

Illustrated Address: Safety Work on the Baltimore and Ohio Railroad, John T. Broderick.

NEW YORK, MARCH 13

Paper: Mobile Armament for Defense, Andrew M. Coyle. Abstract published in THE JOURNAL, August 1917.

BUFFALO, MARCH 14

Karl W. Zimmerschied spoke on the necessity of standardization as a measure of industrial preparedness.

PHILADELPHIA, MARCH 15

Joint meeting with The Franklin Institute. Address: Design, Construction and Equipment of a Modern Military Aeroplane, Jerome C. Hunsaker.

CHICAGO, MARCH 16

General discussion of the problems presented in the training of the young engineer.

MILWAUKEE, MARCH 21

Address by Capt. W. A. Moffat, U.S.N., Commandant of the Navy Training Station at Great Lakes, Ill., advocating the building of sea giants by the United States.

PROVIDENCE, MARCH 26

Subject: Planning-Room Functions, F. E. Cooper.

PHILADELPHIA, MARCH 27

Joint meeting with the Philadelphia Chapter of the American Society of Heating and Ventilating Engineers. Address: District Heating, Walter J. Kline.

PROVIDENCE, MARCH 28

Addresses on The Engineer and Organization by Dr. Ira N. Hollis, President, Am.Soc.M.E., George H. Pegram, President, Am.Soc.C.E., and Harold W. Buck, President, A.I.E.E.

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PHILADELPHIA, MARCH 30

Banquet at the Bellevue-Stratford Hotel, in honor of the 40th anniversary of The Engineers' Club of Philadelphia.

NEW ORLEANS, APRIL 2

Joint meeting with the New Orleans Association of Civil Engineers. Subject: Preparedness, A. M. Lockett. Published in THE JOURNAL, June 1917.

BOSTON, APRIL 4 AND 5

Joint meeting with the American Institute of Electrical Engineers. First session held at the Engineers' Club on the evening of April 4. The technical session was devoted to the general subject of Recent Developments in Steam Generation. Papers: Developments in Fuel Oil vs. Coal, Frederick Ewing; Up-to-date Stoker Practice, Sanford Riley; High Pressures and Temperatures in a Modern Station, I. E. Moultrop; High-Temperature Insulation of Boiler Settings, P. A. Boeck. Prof. L. S. Marks also reviewed the recent work of Messrs. Kreisinger, Ovitz and Augustine on Combustion in Hand-Fired Boilers.

Afternoon session, April 5, on Isolated Plants and Central Stations. Papers: Principal Factors in the Selection of Sources of Power, Walter N. Polakov; Interesting Isolated Power Plants, A. R. Meek; An Isolated Power Plant in Connection with a Factory near Boston, William G. Starkweather; Engineering Features and Results at the Holyoke Municipal Plant, John J. Kirkpatrick; Coöperation Between Isolated Plants and Central Stations, Percival R. Moses and W. F. Schaller.

Evening session, April 5, on Developments of Prime Movers, Condensers, Auxiliary Equipment, Etc. Papers: The Discussion of Engineering Subjects by Engineering Societies, brief address by John A. Stevens; Engineering Features of Combined Heat and Power Distribution, R. A. Langworthy; Turbine Development in Recent Years, brief address by Dr. L. C. Loewenstein; Recent Developments in Condensers and Modern High Vacuum, Charles H. Bromley.

BUFFALO, APRIL 4

Address: Vocational Training, Arthur S. Hurrell.

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CHICAGO, APRIL 4

Dinner Meeting. Address: Oxy-Acetylene Welding, J. Philip Furbeck.

NEW YORK, APRIL 10

Paper: Standards of Business Success, Earle Buckingham.

BIRMINGHAM, APRIL 11

Address: Technical Writing, Prof. M. Thomas Fullan.

ST. LOUIS, APRIL 11

Joint meeting with the Engineers' Club. Paper: Some Unusual Applications of the Diesel Engine, H. R. Setz. Illustrated.

BALTIMORE, APRIL 12

Address: Munitions and Preparedness, Alten S. Miller.

MERIDEN, APRIL 12

Address by E. P. Bullard on the Bullard Machine Company's new employment plan.

BUFFALO, APRIL 18

Paper: A History of Aviation, Charles M. Manly.

ST. LOUIS, APRIL 18

Subject: Refrigeration Problems of a Modern Hotel.

NEW HAVEN, APRIL 19

Spring Meeting. Afternoon Session: Paper: Water Works Pumping Engines, Herbert C. Nickerson, followed by excursions to the large pumping stations at Lake Whitney and Lake Saltonstall.

Evening Session: Papers: The Development of the Centrifugal Pump, F. F. Nickel, illustrated; Pumping Machinery for Industrial Purposes, H. M. Chase, illustrated.

DETROIT, APRIL 20

Dinner, followed by address on Leonardo da Vinci, Artist, Philosopher and Engineer, John W. Lieb.

PROVIDENCE, APRIL 23

Subject: Routing — Principles, Machine Symbols.

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PHILADELPHIA, APRIL 24

Paper: Recent Developments in V-Notch Weir Measurement, D. Robert Yarnall. Illustrated.

BUFFALO, MAY 2

Election of Officers: President, F. A. Lidbury; First Vice-President, D. W. Sowers; Secretary, F. B. Hubbard; Treasurer, W. M. Dollar; Directors, H. B. Alverson, F. E. Cardullo.

PROVIDENCE, MAY 2

Second annual banquet of Providence Engineering Society. Addresses by Mayor Gainer, Capt. M. de Jarny, Capt. Nathan Horowitz, M. S. Davidson, Dr. Ira N. Hollis, President, Am.Soc.M.E., and Prof. Albert Van Hecke.

MERIDEN, MAY 3

Illustrated Lecture: The Steam Turbine, J. Breslav.

NEW YORK, MAY 8

Illustrated Address: The Poppet-Valve Steam Engine, Siegfried Rosenzweig. Published in THE JOURNAL, September 1917.

MINNESOTA, MAY 10

Illustrated Lecture: Coke and Its By-Products, K. C. Richards.

BIRMINGHAM, MAY 16

Annual Meeting. Moving pictures illustrating the old and new methods of cooking — coal vs. electricity, followed by an address by R. E. Brakeman, Section Chairman, giving a review of the progress the past year. Election of Officers: Chairman, J. H. Klinck; Vice-Chairman, W. P. Caine; Secretary, J. G. Hatman; and Paul Wright and R. E. Brakeman.

ST. LOUIS, MAY 16

Subject: The Measuregraph, W. R. Blair.

CHICAGO, MAY 18

Address: The War Situation of Today, S. J. Duncan-Clark.

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PROVIDENCE, MAY 21

Subject: Time and Motion Study.

PHILADELPHIA, MAY 22

Address: Engineering of Men, Willard Beahan.

WORCESTER, JUNE 5

Address by Dr. Ira N. Hollis, President, Am.Soc.M.E., on the war situation.

BUFFALO, JUNE 7

Illustrated talk by Chester L. Lucas on the manufacture of 9.2-in. high-explosive howitzer shells.

WORCESTER, JUNE 28

Motion-picture film shown, representing the manufacture of 9.2-in. howitzer shells.

THE SPRING MEETING

CINCINNATI, OHIO, MAY 21 TO 24

The Spring Meeting of the Society, held in Cincinnati, Ohio, May 21 to 24, with headquarters at the Hotel Sinton, was by far the best attended midyear convention in its history, the total registration being 868, of which 410 were members.

The professional program, in charge of the Committee on Meetings, arranged for seven professional sessions: two munitions sessions, one general session, one machine-shop session, one gas-power session, an industrial-safety session, and one joint session with the National Machine Tool Builders' Association. On account of the lively interest developed in the discussion of the munitions papers, it was found necessary to provide a third session for the purpose.

The joint session with the National Machine Tool Builders' Association was a noteworthy event arranged by the Local Committees to show the consideration which is being given in Cincinnati to the humanitarian side of engineering. The addresses were by Dean Herman Schneider, the exponent of the coöperative system of education so successfully developed at the University of Cincinnati; and by Dr. Otto P. Geier, medical director of the Cincinnati Milling Machine Company, who dealt with the work of the socially minded physician in industry. This joint session was followed by a timely motion-

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picture exhibition, arranged by *Machinery*, showing the processes of manufacture of 9.2-in. shells.

As usual at the Spring Meeting, the Sections of the Society, through their representatives, showed themselves to be very much alive, and enthusiastic conferences were held at which there were members in attendance from eighteen different cities.

The social events began with an informal reception on Monday evening in the ballroom of the Sinton, with an address of welcome by the Mayor of Cincinnati and reply by President Hollis, followed by stereopticon views and dancing. The important social event for members was the smoker on Tuesday evening, while the ladies were entertained by performances specially arranged for the occasion. On Tuesday there was an excursion to Rookwood Pottery and the Art Museum, and in the afternoon an automobile ride to Fort Thomas and a tea at the Hotel Altamont. On Wednesday and Thursday other excursions, shopping trips, automobile rides, etc., were provided. On Wednesday all went on the *Island Queen* to Fernbank Dam and back, and enjoyed a delightful afternoon. A most elaborate entertainment was given on Wednesday evening, after which there was dancing. On Thursday afternoon there was a procession of 160 automobiles bearing the party for an afternoon's outing. Opportunities were also given for visiting the shops of the city, many of which have new and modern structures.

The remarkable success of this meeting in all its features was due to the untiring efforts of the Cincinnati Committee. The members of the Executive Committee for this Society were: Fred A. Geier, Chairman, G. W. Galbraith, Vice-Chairman; John T. Faig, Secretary-Treasurer; W. G. Franz and George Langen; and for the National Machine Tool Builders' Association: J. B. Doan, Chairman; A. H. Tuechter, F. A. Geier and C. W. Walter. A large number of subcommittees were appointed, of which the chairmen were: G. W. Galbraith, Finance and Pictures Committees; J. T. Faig, Publicity and Business Arrangements Committees; H. M. Norris, Entertainment Committee; Mrs. R. K. LeBlond, Ladies' Committee; H. Ritter, Refreshment Committee; J. C. Hobart, Jr., Dancing Committee; A. C. Hoefinghoff, Properties Committee; H. M. Wood, Visits and Costume Committees; J. S. Louis, Assembling Committee; George Langen, Information Bureau; J. B. Stanwood, Reception Committee; C. H. Fox, Motor Car Committee; Thos. Elliott, Transportation Committee; Chas. S. Gingrich, Publication Committee; and R. S. Alter, Decoration Committee.

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PROGRAM

Monday Morning, May 21

Registration of members and guests at headquarters.

Monday Afternoon

Inspection trips to points of interest in the city.

Monday Evening

Informal reception and dance.

Tuesday Morning, May 22

BUSINESS MEETING

Committee reports, discussion, new business.

SIMULTANEOUS PROFESSIONAL SESSIONS

MISCELLANEOUS

TESTS OF UNIFORM STEAM TRACTION ENGINES, F. W. Marquis.

RELATION OF EFFICIENCY TO CAPACITY IN THE BOILER ROOM, Victor B. Phillips.

RADIATION ERROR IN MEASURING TEMPERATURE OF GASES, Henry Kreisinger and J. F. Barkley.

DEVELOPMENT OF SCIENTIFIC METHODS OF MANAGEMENT IN A MANUFACTURING PLANT, Sanford E. Thompson, William O. Lichtner, Keppele Hall and Henry J. Guild.

DISK-WHEEL STRESS DETERMINATION, S. H. Weaver.

MACHINE SHOP SESSION

A FOUNDATION FOR MACHINE TOOL-DESIGN AND CONSTRUCTION, A. L. De Leeuw.

MACHINE-SHOP ORGANIZATION, Fred G. Kent.

METAL PLANERS AND METHODS OF PRODUCTION, Charles Meier.

Excursion to Rookwood Pottery and the Art Museum.

Tuesday Afternoon

JOINT SESSION WITH NATIONAL MACHINE TOOL BUILDERS' ASSOCIATION

THE TREND IN ENGINEERING TRAINING, Dean Herman Schneider.

THE HUMAN POTENTIAL IN INDUSTRY, Dr. Otto P. Geier.

Excursion to Fort Thomas, Ky.

Tuesday Evening

Smoker for members.

Entertainment for ladies.

Wednesday Morning, May 23

FIRST MUNITIONS SESSION

MUNITIONS CONTRACTS AND THEIR FINANCING, Frederick A. Waldron.

ORGANIZING FOR MUNITIONS MANUFACTURE, Arthur L. Humphrey.

ORGANIZATION FOR MUNITIONS MANUFACTURE, Harry L. Coe.

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PROCURING SPECIAL MACHINES FOR MUNITIONS MANUFACTURE, H. V. Haight.

PRACTICAL WARTIME SHELL MAKING, Lucien I. Yeomans.

Inspection trips to points of interest in the city.

Wednesday Afternoon

Boat ride to Fernbank Dam.

Visits to shops.

Wednesday Evening

Entertainment and dance.

Thursday Morning, May 24

SIMULTANEOUS SESSIONS

SECOND MUNITIONS SESSION

MUNITIONS DESIGN FOR QUANTITY MANUFACTURE, J. E. Otterson.

PROCURING MATERIALS FOR MUNITIONS, C. B. Nolte.

LIMITS AND TOLERANCES FOR THE MANUFACTURE OF MUNITIONS, A. W. Erdman.

GAGES AND SMALL TOOLS, Frank O. Wells.

THE IMPORTANCE OF INTELLIGENT INSPECTION IN MUNITIONS MANUFACTURE, E. T. Walsh.

GAS POWER SESSION

THE PROBLEM OF AEROPLANE ENGINE DESIGN, Charles E. Lucke.

TEST OF A MOTOR FIRE ENGINE, Horace Judd.

THE DESIGN OF MOTOR-TRUCK ENGINES FOR LONG LIFE, John Younger.

THE RELATION OF PORT AREA TO THE POWER OF GAS ENGINES AND ITS INFLUENCE ON REGULATION, J. R. DuPriest.

INDUSTRIAL SAFETY SESSION

TENTATIVE DRAFT OF CODE OF SAFETY STANDARDS FOR INDUSTRIAL LADDERS.

TENTATIVE DRAFT OF CODE OF SAFETY STANDARDS FOR POWER-TRANSMISSION MACHINERY.

Inspection trips to points of interest in the city.

Thursday Afternoon

Motor-car ride through Cincinnati parks and suburbs.

Visits to machine shops.

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No. 1584

TESTS OF UNIFLOW STEAM TRACTION ENGINES

By F. W. Marquis, Columbus, Ohio
Member of the Society

This paper presents the results of two series of tests of Baker uniflow steam traction engines, many of them being shown graphically in the form of curves. The steam consumptions of these engines are compared with those representative of the older or counterflow type of engines, and the conclusion is reached that the simple uniflow engine operating non-condensing with saturated steam has a lower steam consumption than the compound counterflow engine under like conditions; and that when operating non-condensing but with superheated steam it will have approximately the same steam consumption as a compound counterflow engine operating condensing on saturated steam.

AT first thought it seems strange to find refinements such as the uniflow cylinder and the superheater in connection with traction engines; but when it is remembered that traction engines are used extensively in certain districts (notably the northwestern part of the United States) where fuel is very expensive, and water has to be hauled many miles, the reason for taking advantage of every means for reducing coal and water consumption becomes apparent.

2 It was therefore with a great deal of interest, in the spring of 1915 and again in the spring of 1916, that tests of Baker uniflow traction engines were undertaken as thesis work by members of the senior class of the Mechanical Engineering Department of The Ohio State University.[1]

DESCRIPTION OF ENGINES TESTED

3 The engine tested in 1916 was almost identical with that tested in 1915, except that in 1916 the boiler was supplied with a

[1] In 1915 the work was done by L. R. Baker, J. F. Buehner, and A. R. Furnas; in 1916 by R. K. Codner, A. F. Landefeld, and C. E. Weir, with the assistance of L. R. Baker.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of The American Society of Mechanical Engineers.

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smokebox-type superheater. The piston displacement of the engine tested in 1916 was 8½ per cent larger than that of the engine tested in 1915 and the water heating surface of the boiler 24½ per cent larger. Both machines were made by the A. D. Baker Company, of Swanton, Ohio, and in accordance with their standard designs, except for the uniflow cylinder and the superheater which were then in process of development.

TABLE 1 PRINCIPAL DIMENSIONS OF BAKER UNIFLOW TRACTION ENGINES

	Engine used in 1915	Engine used in 1916
Engine		
Nominal horsepower	16	18
Nominal r.p.m.	240	240
	In.	In.
Diameter of cylinder	8½	9½
Stroke	10½	10
Diameter of piston rod	1½	1½
Diameter of flywheel	36	38
Face of flywheel	10	11
Diameter of crankshaft	3	3½
Length of crankshaft	55½	61½
Diameter of crankpin	2½	2½
Boiler		
Number of tubes	40	54
	In.	In.
Outside diameter of barrel	29	33
Length of firebox	36	40
Width of firebox	22½	25
Diameter of tubes	2	2
Length of tubes	78	72
	Sq. ft.	Sq. ft.
Grate area	5.56	6.94
Firebox heating surface	23.6	29.1
Tube heating surface	123.2	153.6
Total water heating surface	146.8	182.7
Superheater heating surface	.....	47

4 In Figs. 1 and 2 are views of the engine tested in 1916 as arranged for the tests. The principal dimensions of both engines are given in Table 1. Besides the uniflow cylinder and the superheater, the feature of particular interest is the valve gear, which deserves special attention and will later be described.

CYLINDER AND VALVES

5 Figs. 3 and 4 show cross-sections through the uniflow cylinder and valves. There are triple-ported admission valves, and an

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auxiliary exhaust valve which causes the point of compression to come late in the stroke, instead of at the point where the piston covers the main exhaust ports as is the case with all uniflow engines not provided with some form of auxiliary exhaust valve.

6 The operation of the valves can best be explained by following their movement as the piston moves through one stroke. Suppose the piston to be moving toward the right and nearing the end of its stroke; that is, that it is just a little to the left of its position in Fig. 3. The admission valves (at the top) will then be a little to the right of the position shown, and moving towards the left. The auxiliary

FIG. 1 TRACTION ENGINE EQUIPPED FOR TESTING, IN LABORATORY OF OHIO STATE UNIVERSITY

exhaust valve F (at the bottom of the figure) will be at the extreme right end of its travel, and stationary.

7 When the edge J of the piston uncovers the ports at the center of the cylinder, exhaust commences. About the same time the cavity A in the admission valve uncovers the port at the end of passage B and allows live steam to flow from E (see Fig. 4), through passage B, cavity A and passage D into chamber N at the end of auxiliary exhaust valve F. This causes valve F to move to the extreme left of its travel, closing the auxiliary exhaust port K and opening the auxiliary exhaust port K_1. Exhaust is then taking place both through the main exhaust ports and through auxiliary exhaust port K_1. An instant after the auxiliary exhaust valve moves and

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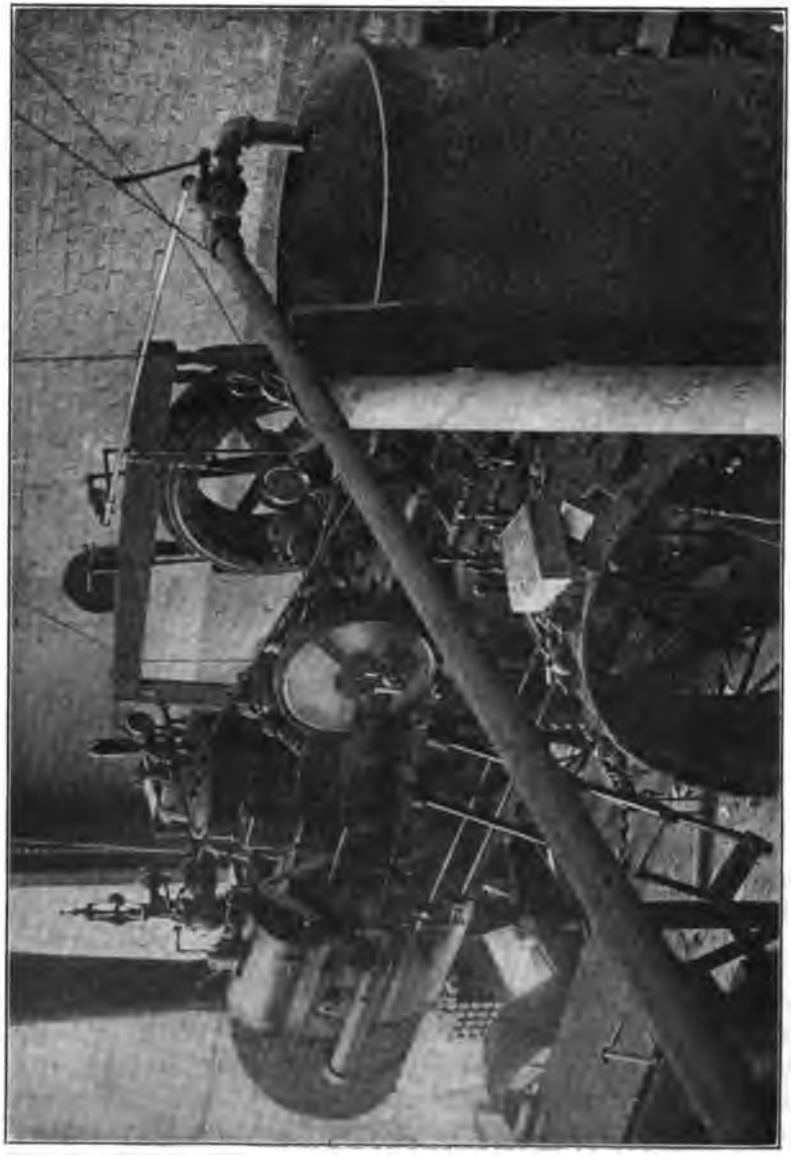

FIG. 2 TRACTION ENGINE IN LABORATORY

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just before the piston reaches the end of its stroke, admission takes place through the three ports C.

8 As the piston starts on the return stroke towards the left, exhaust takes place through the main exhaust ports at the center of the cylinder until, early in the return stroke, they are covered by the piston. The steam still in the cylinder continues to exhaust through auxiliary exhaust port K_1 until the piston covers this port, late in the stroke, when compression starts. Meanwhile live steam has been admitted on the other side of the piston until the admission valve has

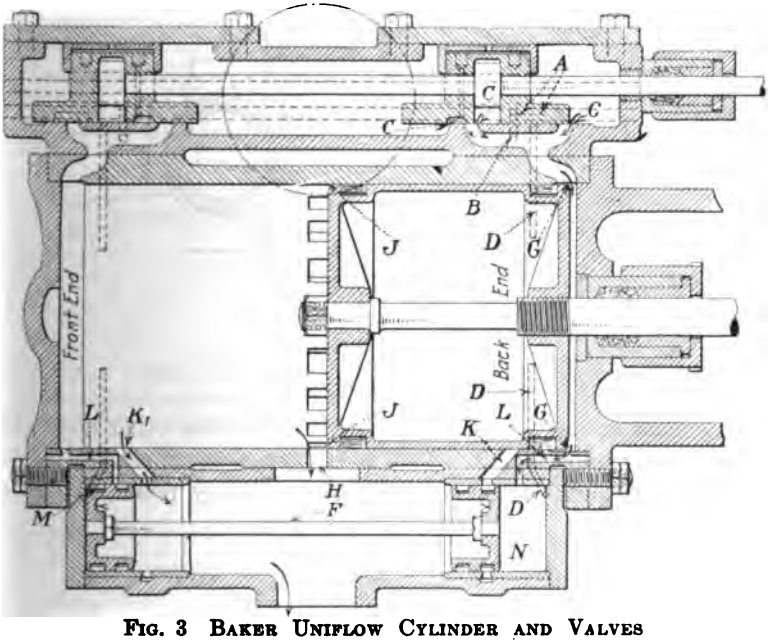

FIG. 3 BAKER UNIFLOW CYLINDER AND VALVES

returned and cut-off has occurred. After cut-off and during expansion, the live steam in chamber N, at the head of the auxiliary exhaust valve, is free to expand through passage L and do work on the piston. This passage L enters the auxiliary exhaust valve chamber at such a point that when the valve is thrown some steam is trapped between it and the end of the valve chamber, thus cushioning it and preventing pounding.

THE VALVE GEAR

9 The admission valves are driven by a Baker valve gear, which is very similar to the Baker gear now being used so extensively in

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locomotive practice. It is a single-eccentric variable cut-off and reversing gear which maintains equal leads for all cut-offs and in both directions of running. It consists of an eccentric arm *A* (Fig.

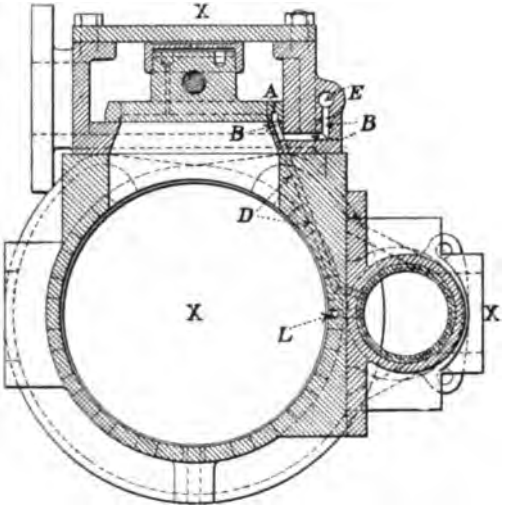

FIG. 4 BAKER UNIFLOW CYLINDER AND VALVES

5) connected at one end to the eccentric and at the other end to the lower end of radius arm *B*. This radius arm is supported at the top by a pin *C* which can be held in place at any point on the arc

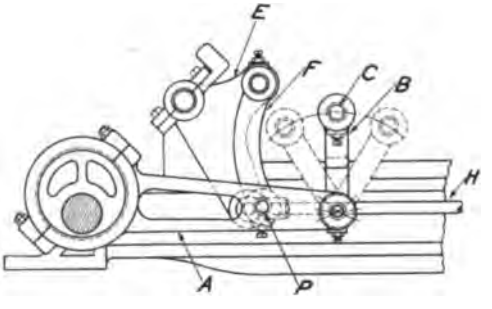

FIG. 5 BAKER VALVE GEAR

shown in Fig. 5 by a reverse yoke. The eccentric arm *A* is connected to a bell crank *E* by means of the connecting rod *F*. The valve rod *H* is attached to the bottom of the bell-crank arm. The eccentric is set exactly 90 deg. ahead of the crank.

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10 When the engine revolves, the eccentric moves one end of the eccentric arm in a circle, and the other end is caused to swing in an arc by the radius arm B. The motion of point P (the point at which the connecting rod F is attached) is then a combination of these two motions. The horizontal arm of bell crank E will then be moved up and down and the vertical arm back and forth, thus driving the valve rod.

11 The point of cut-off is changed and the engine reversed by moving the reverse yoke and thus changing the position of pin C, about

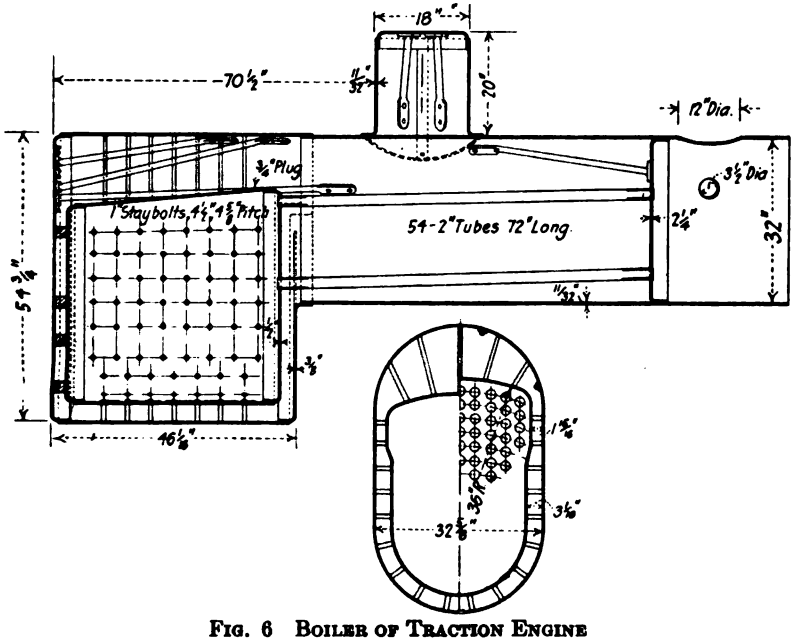

FIG. 6 BOILER OF TRACTION ENGINE

which the radius arm B revolves. When the engine is on center the end of the eccentric arm and the point of support of the reverse yoke are exactly in line, so there is no motion of the eccentric arm (and valve) when the reverse yoke is moved (engine still on center). Thus the lead remains constant for all positions of the reverse yoke, i.e., for all cut-offs.

THE BOILER AND SUPERHEATER

12 In Fig. 6 is a drawing of the boiler used in the 1916 tests. It is almost identical with that used in 1915 except that it is a little larger, having 24½ per cent more heating surface.

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13 In 1916 a superheater was placed in the smokebox. It is shown in place in Fig. 7, and removed in Fig. 8. It consists of a vertical cast-iron header into which tubes are inserted, as shown in Fig. 8. Steam enters through pipe *A*, Fig. 9, which leads from the steam dome and passes to the front section of the header. It then passes back through the ½-in. pipes and forward through the 1½-in. pipes into the back section of the header. Thence it passes through pipe *B* to the steam chest.

METHOD OF PROCEDURE

14 The tests were conducted in the Mechanical Engineering Laboratory of The Ohio State University and in general the methods

FIG. 7 SUPERHEATER IN PLACE IN SMOKEBOX OF BOILER

recommended in the A.S.M.E. Power Test Code were followed. All coal fired was weighed, sampled, analyzed and the calorific value determined. The feedwater was weighed and correction made for injector overflow and other wastes. The quality of steam was taken by means of a Barrus throttling calorimeter, the sampling pipe being located in the path of the steam as it left the steam dome. Smokebox temperatures were determined by means of a thermocouple and the smokebox gases were sampled continuously and analyzed by means of an Orsat apparatus. Indicated and brake horsepower and revolutions per minute were all carefully determined. All instruments were calibrated and corrections applied where necessary.

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15 The tests were run with the throttle valve wide open, and except where otherwise noted it was attempted to maintain the

FIG. 8 SUPERHEATER REMOVED FROM BOILER

speed constant at 250 r.p.m. During the preliminary running preceding each test the brake load was adjusted so that the desired

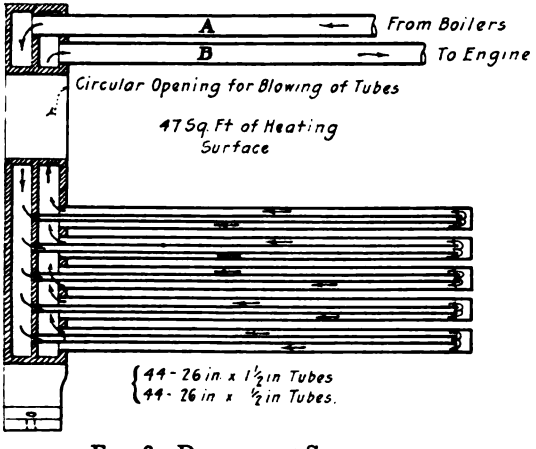

FIG. 9 DIAGRAM OF SUPERHEATER

speed was obtained when the throttle valve was wide open. During each run all conditions were maintained as constant as possible.

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PROGRAM OF TESTS

16 *First Series.* The 1915 series consisted of 17 tests with various boiler pressures ranging from 125 lb. gage to 175 lb. gage, and various cut-offs ranging from 6 per cent to 49 per cent of the stroke. Saturated steam was used throughout this series, and the approximate speed was 250 r.p.m. in all tests.

17 *Second Series.* The 1916 series consisted of 17 tests, 13 at 180 lb. gage and 4 at 160 lb. gage. Nine of the former were with superheated steam, and four with saturated steam. Superheated steam was used for the four latter tests. The cut-off in this series

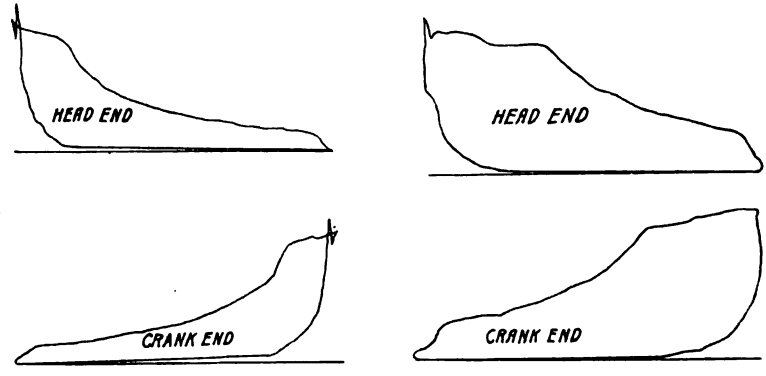

FIG. 10 SAMPLE INDICATOR DIAGRAMS

varied from 16 per cent to 75 per cent of the stroke. The approximate speed was 240 r.p.m., with the exception of three short runs which were made with variable speed to secure data concerning the relation between speed and power.

RESULTS

18 A summary of the results having to do with engine performance is given in Table 2, and in Table 3 will be found a summary of results having to do with the boiler and with the overall performance. Many of these results are also presented graphically in Figs. 11, 12 and 13.

19 In Fig. 10 are two sample sets of indicator diagrams, one with a rather early and the other with a much later cut-off. They show

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a remarkable lack of wire-drawing during admission, and sharp cut-off for a slide-valve engine running at such a high speed (250 r.p.m.). The drop in the early part of the expansion line of the diagrams with an early cut-off, and that in the admission line of the diagrams with the later cut-off, is caused by the steam flowing into the auxiliary exhaust-valve chamber at the instant the piston uncovers the port leading to this chamber.

20 The curves in Fig. 11 show the relation between steam consumption in pounds per i.hp-hr. and i.hp. for both the series of 1915 and the series of 1916, under the different conditions of running. Reference to this figure shows that the highest steam consumption

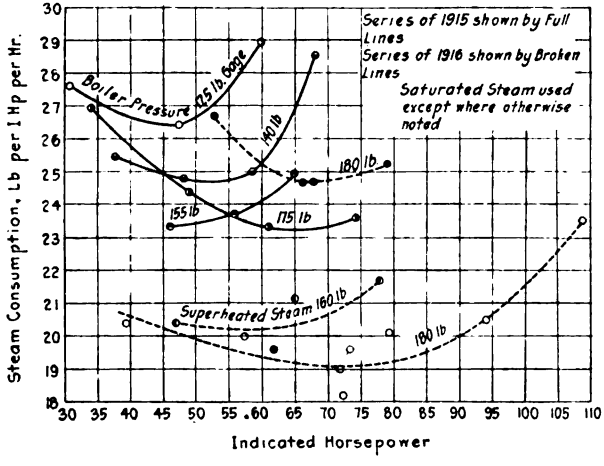

FIG. 11 CURVES SHOWING RELATION BETWEEN STEAM CONSUMPTION AND INDICATED HORSEPOWER

obtained was just under 29 lb., which occurred at 125 lb. boiler pressure with saturated steam and at approximately 60 i.hp. The lowest steam consumption obtained in any single test was 18.2 lb. per i.hp-hr., in the series of 1916, with 180 lb. boiler pressure and 118 deg. superheat, at about 72 i.hp. Reference to the curve shows, however, that this point was abnormally low, the lowest point on the curve being 19.1 lb. per i.hp. per hour.

21 The total range of steam consumption, from the most unfavorable conditions of high overload and low boiler pressure (125 lb.) with saturated steam, to the most favorable conditions of economical load and high boiler pressure (180 lb.) with superheated steam, was only from 29 to 19 lb., or 10 lb.

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TABLE 2 SUMMARY OF ENGINE RESULTS

Laboratory symbol	Length of test, min.	R.p.m.	Boiler press., lb. per sq. in. gage	Superheat, deg. fahr.	Avg. cut-off, per cent of stroke	I.hp.	B.hp.	Mech. eff'y	Wt. of dry steam per i.hp. per hr., lb.	Wt. of dry steam per b.hp per hr., lb.	Eff'y ratio based on i.hp., per cent
1	2	3	4	5	6	7	8	9	10	11	12
SERIES OF 1915											
1-125-1	300	246.9	125.6	0	15.1	30.75	27.8	90.4	27.65	30.55	55.9
2-125-3	240	252.3	125.2	0	31.7	47.38	42.8	90.4	26.45	29.25	58.3
3-125-5	180	259.3	125.0	0	48.9	59.90	54.3	90.9	28.95	31.92	53.7
4-140-1	240	247.6	141.5	0	15.1	37.58	32.8	87.4	25.45	29.15	58.5
5-140-3	180	269.5	139.5	0	31.7	58.48	52.2	89.4	25.00	28.00	60.0
6-140-2	210	263.6	140.7	0	22.3	47.95	42.0	87.7	24.80	28.25	59.7
7-140-5	180	242.0	140.3	0	49.0	68.01	61.2	90.1	28.55	31.75	51.6
8-155-1[1]	240	258.0	155.6	0	15.1	45.82	37.8	82.6	23.35	28.25	61.3
9-155-3	180	254.6	154.7	0	28.1	64.82	56.7	87.6	24.95	28.50	57.6
10-155-2	240	260.0	155.0	0	20.4	55.63	46.4	83.4	23.72	28.77	60.4
11-165-3	180	253.7	165.2	0	28.1	70.00	61.6	88.0	24.40	27.73	57.3
12-165-1	210	260.5	165.0	0	12.0	45.36	39.0	86.1	25.18	29.24	55.8
13-165-2	180	270.0	165.2	0	20.4	59.04	51.8	87.8	.....	.....	.....
14-175-1	210	251.7	176.2	0	12.0	48.83	42.7	87.5	24.40	27.90	56.0
15-175-2	180	256.4	175.5	0	20.4	60.93	54.8	90.1	23.32	25.90	59.1
16-175-3	180	258.7	176.4	0	28.1	74.12	66.6	89.8	23.60	26.25	58.3
17-175-0	60	244.8	176.2	0	6.2	33.98	28.0	82.5	26.95	32.65	51.2
SERIES OF 1916											
1-160-3	180	238.5	160.0	124	30.6	61.60	55.9	90.8	19.6	21.6	66.0
2-160-4	180	226.0	160.0	130	41.8	64.90	60.8	95.2	21.2	22.7	60.0
3-160-2	180	232.1	159.5	115	21.3	46.80	42.8	91.5	20.4	22.4	63.0
4-180-1	240	253.0	180.0	115	16.7	39.30	34.2	87.0	20.4	23.4	61.5
5-180-2	240	243.0	178.5	117	21.3	57.30	53.3	93.1	20.0	21.5	62.7
6-180-3	180	245.0	178.3	123	30.6	71.80	65.9	91.8	19.0	20.6	65.4
7-180-4	180	227.0	179.5	136	41.8	79.20	73.3	92.5	20.1	21.8	61.4
8-160-5	180	240.2	158.3	142	50.8	77.90	74.0	95.0	21.7	23.8	60.0
9-180-5	180	253.8	177.4	157	50.5	94.10	87.0	92.5	20.5	22.2	59.2
10-180-3[2]	60	282.3	178.6	131	30.6	73.40	67.6	92.2	19.6	21.3	63.5
11-180-3[2]	60	230.1	180.0	118	30.6	72.30	68.2	94.3	18.2	19.3	67.6
12-180-3[2]	15	257.0	180.0	127	30.6	71.30	66.1	92.8	.....	.....	.....
13-180-8[2]	30	294.6	181.0	181	74.7	108.70	102.8	94.5	23.5	24.5	58.5
14-180-2	180	240.8	179.3	0	21.3	52.70	49.4	93.7	26.7	28.1	50.9
15-180-3	180	245.0	179.0	0	30.6	67.60	64.7	95.8	24.7	25.6	55.2
16-180-4	120	245.0	178.5	0	41.8	79.00	74.0	93.7	25.7	27.2	50.3
17-180-3	180	238.0	178.7	0	30.6	66.20	62.8	94.8	24.7	25.7	56.6

Column 1: Laboratory Symbol. The first term represents the number of run; the second the approximate boiler pressure and the last the position of the reverse lever upon its quadrant expressed in notches from the center back.

Column 12: Efficiency ratio, based on i.hp. This is the ratio between the thermal efficiency of the engine and the thermal efficiency of a perfect engine operating on the Rankine complete expansion cycle. It is equal to $2545/WH$, where W = actual wt. of steam per i.hp-hr., and H = the adiabatic heat drop from pressure and quality of steam furnished to engine to exhaust pressure.

[1] Valve setting changed between runs No. 8 and No. 9.

[2] Runs No. 10, No. 11, and No. 12 are short variable-speed runs. Run No. 13 is a short maximum-power run.

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TABLE 3 SUMMARY OF BOILER AND OVERALL RESULTS

Laboratory symbol	Length of test, min.	Boiler press., lb. per sq. in., gage	Superheat, deg. fahr.	Pounds of coal fired per sq. ft. of grate surface per hr.	Equiv. evap'n per sq. ft., water-heating surface per hr., lb.	Equiv. evap'n per sq. ft. total (inc. superheater) heating surface per hr., lb.	Equiv. evap'n per lb. air-dry coal, lb.	Efficiency of boiler per cent	Wt. of air-dry coal per b. hp. per hr., lb.	Overall efficiency, per cent
1	2	4	5	13	14	15	16	17	18	19
SERIES OF 1915										
1-125-1	300	125.6	0	22.2	7.62	.....	8.38	57.1	4.67	3.85
2-125-3	240	125.2	0	32.0	11.00	.....	8.45	57.5	4.35	4.10
3-125-5	180	125.0	0	46.1	15.25	.....	8.11	55.2	4.94	3.63
4-140-1	240	141.5	0	25.1	8.59	.....	8.41	57.4	4.45	4.02
5-140-3	180	139.5	0	39.6	12.97	.....	8.02	54.6	4.41	4.04
6-140-2	210	140.7	0	31.6	10.62	.....	8.26	56.3	4.36	4.11
7-140-5	180	140.3	0	53.6	16.90	.....	7.77	52.8	5.10	3.52
8-155-1	240	155.6	0	27.7	9.63	.....	8.46	57.6	4.28	4.18
9-155-3	180	154.7	0	45.0	14.10	.....	7.83	53.3	4.58	3.92
10-155-2	240	155.0	0	36.2	11.61	.....	7.96	54.4	4.53	3.94
11-165-3	180	165.2	0	48.9	14.89	.....	7.57	51.5	4.58	3.90
12-165-1	210	165.0	0	31.8	10.10	.....	7.84	53.4	4.74	3.77
13-165-2	180	165.2	0	38.1	.....	.....	.....	.....	4.29	4.17
14-175-1	210	176.2	0	33.0	10.50	.....	7.88	53.6	4.51	3.98
15-175-2	180	175.5	0	39.7	12.40	.....	7.74	52.6	4.23	4.25
16-175-3	180	176.4	0	49.6	15.20	.....	7.58	51.7	4.34	4.14
17-175-0	60	176.2	0	21.3	8.72	.....	8.87	60.3	4.44	4.04
SERIES OF 1916										
1-160-3	180	160.0	124	27.1	8.12	6.92	8.43	58.6	3.40	5.38
2-160-4	180	160.0	130	32.6	9.13	7.90	7.95	55.3	3.76	4.80
3-160-2	180	159.5	115	22.1	6.47	5.54	8.34	57.9	3.54	5.14
4-180-1	240	180.0	115	18.5	5.47	4.68	8.47	58.8	3.73	4.90
5-180-2	240	178.5	117	26.6	7.71	6.62	8.36	58.0	3.42	5.32
6-180-3	180	178.3	123	31.3	9.13	7.80	8.45	58.7	3.23	5.65
7-180-4	180	179.5	136	37.2	10.65	9.14	8.16	56.7	3.51	5.19
8-160-5	180	158.3	142	38.8	11.26	9.56	8.27	57.5	3.62	5.04
9-180-5	180	177.4	157	45.1	12.80	11.04	8.18	56.8	3.30	5.11
10-180-3	60	178.6	131	32.8	9.60	8.23	8.35	58.0	3.35	5.45
11-180-3	60	180.0	118	29.4	8.74	7.49	8.48	58.9	2.98	6.13
12-180-3	15	180.0	127	.....	.....	.....	.....	.....	.....	.....
12-180-3	30	181.0	181	63.6	16.77	14.72	7.20	50.0	4.58	3.98
14-180-2	180	179.3	0	26.9	8.71	.....	8.24	57.2	3.83	4.77
15-180-3	180	179.0	0	36.6	11.15	.....	7.97	56.4	3.92	4.64
16-180-4	120	178.5	0	42.8	13.38	.....	7.36	51.4	4.50	4.06
17-180-3	180	178.7	0	35.4	10.80	.....	8.18	56.8	3.86	4.73

Column 1: Laboratory Symbol. The first term represents the number of run; the second the approximate boiler pressure, and the last the position of the reverse lever upon its quadrant expressed in notches from the center back.

Columns 16 and 17: The superheater, when used, is considered to be a part of the boiler.

Column 19: Overall Efficiency. The ratio between the heat equivalent of the work done at the brake pulley per lb. of air-dry coal fired and the heat value per lb. of air-dry coal.

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22 It will be noticed that at each boiler pressure tests were run with cut-offs considerably later than the most economical. It seems reasonable to assume that the engine should be rated at approximately the point of best economy. On this basis the rating when operating under 125 lb. boiler pressure would be 45 hp. Tests were run from about 30 to about 60 i.hp. or from about 60 per cent to 130 per cent of this rated load, and over this range the variation in steam consumption was from approximately 29 to 26½, or only about 2½ lb.

23 If the same reasoning is followed in connection with the tests run at 180 lb. boiler pressure and with superheated steam it

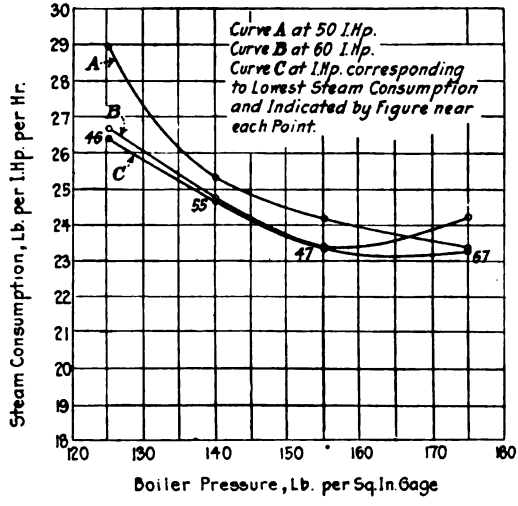

FIG. 12 CURVES SHOWING RELATION BETWEEN STEAM CONSUMPTION AND BOILER PRESSURE, SERIES OF 1915

will be found that tests were run over a range of from approximately 55 per cent to 145 per cent of full load, and that the maximum difference in steam consumption over this rather wide range was only from approximately 20½ to 23½ lb., or 3 lb.

24 It is interesting to note that the maximum power obtained was 108.7 i.hp. (102.8 b.hp.) which was obtained with 180 lb. boiler pressure and with 181 deg. fahr. superheat, and with a steam consumption of only 23.5 lb. per i.hp. per hour (24.5 lb. per b.hp. per hour). This becomes particularly interesting when it is remembered that the cylinder diameter and stroke of this engine were only 9¼ in. and 10 in. respectively.

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25 The curves in Fig. 12 show the relation between steam consumption and boiler pressure. As the boiler pressure increases, not only does the steam consumption decrease, but also the power at any cut-off, and the power at which the lowest steam consumption occurs increases. Curve *A* shows the decrease in steam consumption with increase of boiler pressure at 50 i.hp., and curve *B* at 60 i.hp. Curve *C* shows the relation between the minimum steam consumption at each boiler pressure, and the boiler pressure. The power corresponding to minimum steam consumption at each pressure is shown by the figure near each point through which this curve

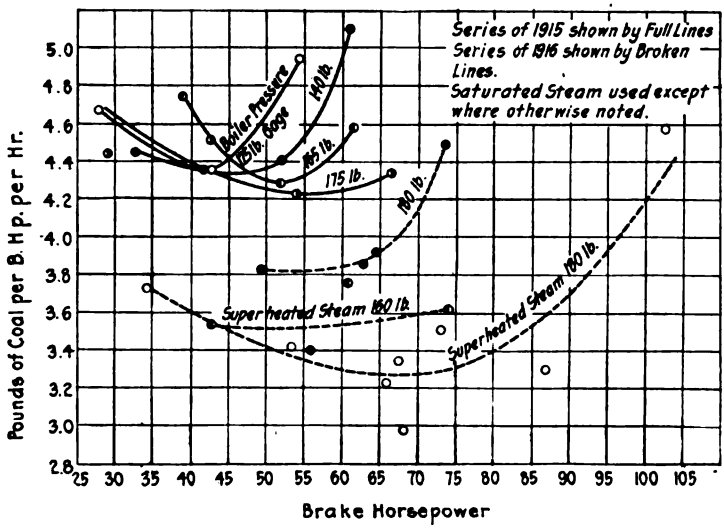

FIG. 13 CURVES SHOWING RELATION BETWEEN POUNDS OF COAL PER BRAKE HORSEPOWER PER HOUR AND BRAKE HORSEPOWER

is drawn. It will be noticed that, with the exception of one point on this curve, the power of minimum steam consumption increases as the boiler pressure increases.

26 Curve *A* shows that at 50 hp. the steam consumption decreases from 29 lb. at 125 lb. to 23.4 lb. at 175 lb. pressure, while curve *C* shows that, if the point of minimum steam consumption at each boiler pressure is taken, the decrease is only from 26.4 lb. at 125 lb. pressure to 23.3 lb. at 175 lb. pressure.

27 The curves of Fig. 13 show the relation between the pounds of coal used per brake horsepower per hour and the brake horsepower developed. These curves are naturally of the same general shape

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as those given in Fig. 11 showing the relation between steam consumption and indicated horsepower. The inconsistency in results shown by the fact that many points are not located on the curves is caused largely by the facts that it was not possible to maintain uniform conditions of combustion during the different tests, and that it was very difficult to keep the condition of the fuel bed such that there would be the same amount of coal on the grates at the end as at the beginning of a run.

28 It will be noted that the highest coal consumption was 5.1 lb. per b.hp-hr., and that this occurred at 140 lb. boiler pressure

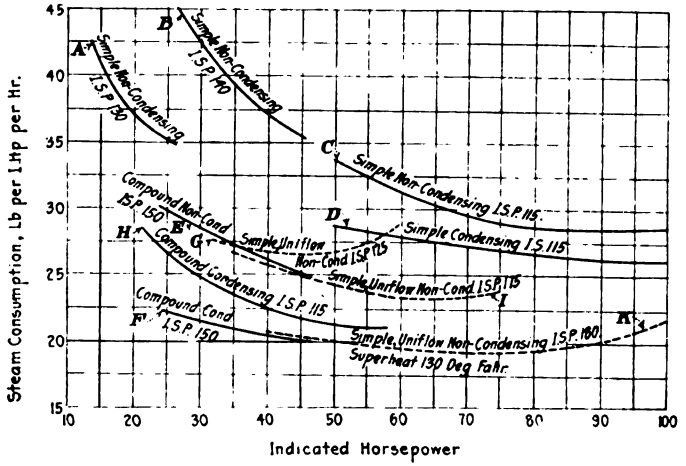

FIG. 14 RELATIVE STEAM CONSUMPTION OF BAKER UNIFLOW ENGINES AND COUNTERFLOW ENGINES

and 61 b.hp., while the lowest coal consumption obtained in any single test was 2.98 lb. per b.hp-hr., which occurred at 180 lb. boiler pressure, 118 deg. fahr. superheat, and 68 b.hp. However, this seems to be an abnormally low value, the lowest point on any curve being 3.27 lb., corresponding to 180 lb. boiler pressure with superheated steam and at 67.5 b.hp.

29 As a matter of interest from a comparative point of view, the steam-consumption curves of a number of the ordinary counterflow type of steam engines, both simple and compound, non-condensing and condensing, have been plotted on the same sheet with certain of the steam-consumption curves of the Baker uniflow engine. These curves are given in Fig. 14. Information concerning

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each of the engines whose steam-consumption curve is given in this figure will be found below.

Curve *A*. Simple, slide-valve engine, cylinder 8 in. by 12 in., initial steam pressure 130 lb. gage, non-condensing, and at 200 r.p.m.

Curve *B*. Simple, slide-valve engine, cylinder 9 in. by 12 in., initial steam pressure 140 lb. gage, non-condensing, and at 290 r.p.m.

Curve *C*. Simple, slide-valve engine, cylinder 15 in. by 14 in., initial steam pressure 115 lb. gage, non-condensing, and at 225 r.p.m.

Curve *D*. Same engine as in case of curve *C*, but operating condensing.

Curve *E*. Cross-compound, slide-valve engine cylinders 7 in. and 13 in. by 10 in., initial steam pressure 150 lb. gage, non-condensing, and at 310 r.p.m.

Curve *F*. Same engine as in case of curve *E*, but operating condensing.

Curve *H*. Tandem-compound, slide-valve engine, cylinders 8½ in. and 13½ in. by 12 in., initial steam pressure 115 lb. gage, condensing, and at 280 r.p.m.

Curve *G*. Simple uniflow engine, cylinder 8¾ in. by 10½ in., initial steam pressure 125 lb. gage, non-condensing, and at 250 r.p.m.

Curve *I*. Same engine as in case of curve *G*, but with 175 lb. gage boiler pressure.

Curve *K*. Simple uniflow engine, cylinder 9½ in. by 10 in., initial steam pressure 180 lb. gage, superheat approximately 130 deg. fahr. non-condensing, and at approximately 240 r.p.m.

COMPARISONS AND CONCLUSIONS

30 It will be seen that the uniflow-engine curves selected are those representing the poorest and the best results obtained with saturated steam, and the best results obtained with superheated steam.

31 A study of this set of curves (Fig. 14) shows that the poorest results obtained with the uniflow engine, namely, those of curve *G*, obtained with saturated steam at 125 lb. pressure, are better than the best results obtained with any of the simple engines, even when operating condensing, and almost the same as those obtained with the compound non-condensing engine shown by curve *E*. The steam consumption of the uniflow engine at 175 lb. pressure with saturated steam running non-condensing is lower than that obtained with the compound non-condensing engine at 150 lb. pressure shown by curve *E*. Also the steam consumption of the uniflow engine with 180 lb. steam pressure and 130 deg. superheat was lower than that of the compound condensing engine with 150 lb. steam pressure shown by curve *F*.

32 Thus it is seen that on the basis of the results of the tests

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reported in this paper and the information presented by Fig. 14, which is thought to represent fairly the average practice for small simple and compound engines of the older or counterflow type, the simple uniflow engine operating with saturated steam and non-condensing is able to surpass in economy of steam consumption the compound counterflow engine when operating under similar conditions. Also that the simple uniflow engine operating non-condensing but with superheated steam will have approximately the same, or slightly less, steam consumption than the compound counterflow engine operating condensing but with saturated steam.

33 On the basis of these conclusions it seems probable that the simple uniflow engine will prove a serious competitor of the compound counterflow type, since it is not only more economical in its use of steam, but also simpler in construction, and probably on that account lower in first cost.

DISCUSSION

E. T. Adams (written). A moderate-power steam traction engine weighs at least 300 lb. per hp. It is therefore far too heavy for ordinary farm work and is really a portable power plant, with its earning power practically limited to the threshing season. It is another example of a type of machine all too common on the farm which disintegrates from idleness rather than from use. The short earning and long rusting seasons are the vital disease affecting the traction engine. The remedy is a longer earning season, which may be secured by any change which will reduce the weight of these machines to a figure approaching 100 lb. per hp., thus making them available for plowing, disking, harrowing and seeding, as well as for threshing and other belt work. Increased economy could make this possible, but a minor increase would not be sufficient — it would have to be great enough to reduce greatly the size of the boiler, or even allow the use of a new type.

The A. D. Baker Company certainly deserve great credit for their endeavors to improve the economy of the farm tractor and have made a step in the right direction, because, although their coal consumption per b.hp-hr. in these tests was greater than that shown on single-cylinder tractors at the Canadian Industrial Exhibition tests in Winnipeg in July 1913, the steam consumption per i.hp-hr. is about 8 per cent better when operating under the same conditions.

It seems too bad, however, that they did not go a step further.

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Their engine is undoubtedly a uniflow engine to the extent that it takes steam at the end of the cylinder and exhausts at the center, but it does not use the thermal cycle which has made the engine commonly known as the uniflow engine so popular in Europe and, more recently, in this country.

The advantage of this European thermal cycle is illustrated by comparison of these tests of the Baker engine with tests made by Government-licensed engineers on a portable engine of approximately the same horsepower and under the same conditions, built by the Maschinenfabrik Badenia, of Weinheim. The Badenia engine had a normal brake horsepower of 120. The steam pressure was slightly lower and the superheat slightly higher than in the Baker engine. The Badenia engine showed an economy of 13.8 lb. of steam per i.hp-hr. and 1.83 lb. of coal per b.hp-hr. The Baker engine therefore required 38 per cent more steam per i.hp-hr. and about 80 per cent more coal per b.hp-hr.

The author does not give the heat value of the coal used in the trials, so it is impossible to get a close basis of comparison on the coal consumption. The coal used at Winnipeg had a heat value of 14,470 B.t.u., and on the trials of the Badenia engine the heat value of the coal used was 13,800 B.t.u. It will be noted that both the Winnipeg and Badenia trials were made by experts not in any way interested in the engines being tried.

J. E. Emswiler (written). It would seem preferable, in most cases, to refer the steam consumption in the curves to b.hp. instead of i.hp., and especially so in these tests, where considerable discrepancy appears if the f.hp. is plotted on b.hp. Such discrepancy must necessarily be blamed upon the i.hp. rather than upon the b.hp., since the latter is much more simply and easily determined in the tests.

Table 2 for the 1916 series furnishes some valuable information concerning the influence of superheat on steam consumption for a uniflow engine.

Test 7–180–4 was made with a load of 73.3 b.hp. and a superheat of 136 deg. Correcting the steam consumption to a load of 74 b.hp. (on a tentative steam-per-hour-per-b.hp. curve — not shown) gives a steam consumption per b.hp-hr. of 21.8 lb. Test 16–180–4 at a load of 74 b.hp. gives a steam consumption per b.hp-hr. of 27.2 lb. at 0 deg. superheat. This is a gain of 5.4 lb. for 136 deg. superheat, or 24.7 per cent, which is 18.2 per cent per 100 deg.

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Again, test 10–180–3², at a load of 67.6 b.hp. and a superheat of 131 deg., shows a steam consumption of 21.3 lb. per b.hp-hr. Correcting in a similar manner to a load of 64.7 b.hp., the steam consumption becomes 21.6 lb. Test 15–180–3, at a load of 64.7 b.hp. and 0 deg. superheat, gives a steam consumption of 25.6 lb. per b.hp-hr. This is a gain of 4.0 lb. for 131 deg., or 18.5 per cent, which is 14.2 per cent per 100 deg.

The average of the two examples is 16.2 per cent per 100 deg. of superheat, based on the steam consumption which accompanies the superheat.

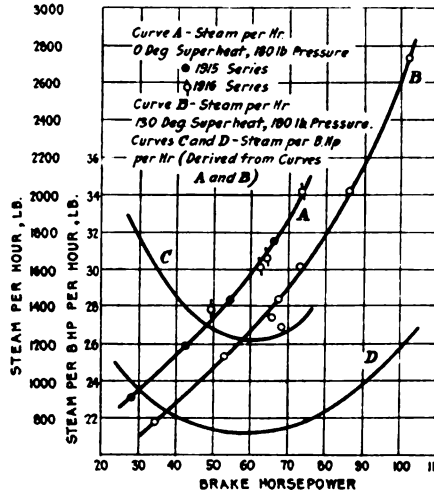

FIG. 15 REPLOT OF AUTHOR'S CURVES

Applying this correction factor to reduce the tests made with superheated steam to a common basis of superheat, say, 130 deg., and plotting corrected steam per hour against b.hp., the curve *B* of Fig. 15 is obtained.

The curve *A* is obtained by plotting the steam per hour of the tests of both the 1915 and 1916 series, at 180 lb. pressure and 0 deg. superheat, against b.hp.

It is very instructive to plot the total steam per hour against the output, as is done in Fig. 15, for two reasons. In the first place, where a number of points are available, as is the case here, such curves serve to distinguish those tests which are probably in error from some cause or other, from those which are accurate. It is

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evident from the curves in Fig. 15 that some discrepancy exists in connection with tests 6–180–3, 11–180–3², and 14–180–2.

In the second place, these curves are instructive as exhibiting a characteristic of the uniflow engine different from that of either a counterflow engine or a steam turbine. The steam-per-hour curve of the uniflow engine has a marked and continuous bend; while for the counterflow engine, or steam turbine, the curve is usually straight, at least for the greater part of its length.

The indicator diagrams of Fig. 10 show a rise in the back pressure from the time the central exhaust ports are closed by the piston until the auxiliary exhaust port is closed. This is probably due to wire-drawing in the auxiliary exhaust port and represents some loss. Undoubtedly, from the standpoint of economy alone, the engine would be better without the auxiliary port, that is, operating on the strictly uniflow principle. However, it is presumable that the purpose of the additional port is to secure greater capacity, which it does by giving thicker diagrams than would be obtained without it.

I note that the percentage of moisture which the steam actually carried is not given in Table 2, but the superheat is given as 0 deg. and the steam is referred to as dry in columns 10 and 11. I should like to ask the author if there was any moisture in the steam, and if so, what factor he applied in correcting the steam to 100 per cent quality.

GEORGE H. BARRUS (written). The term "uniflow" as used in the paper is a misnomer, for the engine described embodies a combination of the uniflow and counterflow principles, with the latter predominating. In a purely "uniflow" engine the exhaust steam passes out through ports located midway between the two ends of the cylinder. In the engine described there are two sets of ports, one located at the middle and the other at or near the ends. With light loads the larger part of the exhaust steam goes through the end ports, counterflow style. With medium and heavy loads quite as much steam goes through the end ports, counterflow style, as through the central ports. The tests reported are not therefore tests of a "uniflow" engine, but are tests of what might well be called a counterflow-uniflow engine, with the counterflow features in the lead.

There is nothing in the paper, so far as I can see, showing that the uniflow characteristics possessed by the Baker engine have anything to do with the superior economy reported. In fact, I cannot see that these characteristics are sufficiently pronounced to produce any

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marked influence on the results. The indicator diagrams are not materially different from those that would be given by any counterflow engine having the same valve gear and working under the same pressure and speed.

To justify the conclusion that the superior results given are due to any uniflow characteristic, a comparison should be made between the engine in question and an ordinary counterflow engine having the Baker valve gear, but the paper makes no such comparison. All that the paper shows, to my mind, is the difference in economy between an engine having excellent steam distribution, such as that obtained by the Baker valve gear, and ordinary throttling slide-valve engines having defective steam distribution, which at best give very poor economy.

TABLE 4 PRINCIPAL DIMENSIONS OF HUBER TRACTOR

Boiler		Engine	
Number of tubes	18	Nominal horsepower	18
Outside diameter of shell, in.	41	Nominal speed, r.p.m.	220
Length of shell, in.	100	Diameter of cylinder, in.	9
Diameter of tubes, in.	3	Stroke, in.	11
Diameter of large flue at front, in.	24	Diameter of piston rod, in.	1¾
Diameter of large flue at rear, in.	27	Diameter of flywheel, in.	36
Grate area, sq. ft.	6.59	Face of flywheel, in.	10
Total water heating surface, sq. ft.	173		

If the title of the paper were changed to read Tests of Counterflow-Uniflow Steam Traction Engines, and the term "counterflow-uniflow" were substituted for "uniflow" throughout, the conclusions would be less liable to be misconstrued than they are in its present form.

L. V. LUDY (written). A few years ago the writer was called upon to conduct a series of tests on a Huber steam tractor, which gave some very interesting information. The results of these tests are presented herewith for comparison with those reported in the paper.

The engine was fitted with a common D-slide valve which was unbalanced. The boiler was of the marine type, having a large flue extending throughout the entire length of the boiler, the back end of which served as a firebox. No superheater was provided. The method employed in carrying out the tests was exactly similar to that used by the author.

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Table 4 gives the principal dimensions of the tractor; and Tables 5 and 6 the general results obtained.

In the results reported by the author the maximum i.hp. in per cent of the normal rated hp. is unusually high, being over 460 per cent for the 1915 engine and about 600 per cent for the 1916 engine. Similar results reported by the writer gave this ratio of the greatest i.hp. to the normal rated hp. to be over 230 per cent, but in this case the engine was not operated at maximum load.

R. J. S. PIGOTT (written). In considering the curves of water rate and boiler efficiency the writer has found it expedient to make

TABLE 5 SUMMARY OF ENGINE RESULTS

Length of test, min.	R.p.m.	Boiler pressure, lb. per sq. in., gage	Average cut-off in per cent of stroke	I.hp.	Dry steam per i.hp. per hr., lb.
60	227.0	110.8	35 8	28.06	28.7
120	217.3	111.7	46.5	37.68	29.7
60	206.3	112.4	53.1	42.21	29.8

TABLE 6 SUMMARY OF BOILER RESULTS

Length of test, min.	Boiler pressure, lb. per sq. in., gage	Coal fired per sq. ft. of grate surface per hr., lb.	Equiv. evap. per sq. ft. water heating surface per hr., lb.	Equiv. evap. per lb. air-dry coal, lb.
60	110.8	14.3	5.58	10.25
120	111.7	24.5	7.75	8.30
60	112.4	27.1	8.72	8.44

use of the input and output, or Willans, line rather than the water-rate or efficiency curves.

In the first place, the Willians line for all throttle-governed engines, and for all turbines, up to the point where the relay valve opens, is substantially straight. For the automatic engine the line is represented by an equation of the second degree, and is curved upward more or less. The valuable feature is that as these Willans lines are either straight or only slightly curved, and the zero steam consumption always falls within reasonably well-defined limits — say 15 to 20 per cent of full-load steam consumption — the direction of the curve can be very much more definitely settled, especially if the tests vary considerably from average. The water-rate curve can then be plotted from the Willans line.

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One feature in Fig. 12 which seems peculiar is the crossing of the lower boiler-pressure curves by the 175-lb. curve at low loads. This is very unusual, as in all cases the writer has seen, the raising of the boiler pressure improves the water rate and lowers the Willans line at all loads. The crossing of the water-rate curves indicates that the Willans line also crosses those at the lower pressures, giving a high no-load steam consumption, which is extraordinary. He would in general suspect an error, especially as the tests seem short for accurate results by the feedwater method. Quite large errors are introduced by the capacity of the system and the impossibility of getting accurate indications of water content of the boilers by gage glasses; the shorter the test, the larger the effect of the error.

A further suggestion to the author is that the results be computed in thermal efficiency, Rankine-cycle efficiency ratio, and B.t.u. per hr., all referred to brake horsepower; the variations with i.hp. are of little value for a comparison with other types of prime mover.

The thermal efficiency is a basic measure of the real economy; so is B.t.u. per b.hp-hr. Water rates are not basic and vary with every set of steam conditions. The Rankine-cycle efficiency ratio is a valuable means of comparing the design of one engine with another, since it shows how well the engine makes use of its steam range, although the thermal efficiencies may be very different. For instance, the efficiency ratio of a non-condensing compound engine may be as high as 75 or 80 per cent, and its thermal efficiency only 7 to 10 per cent; that of a condensing compound, 55 to 60 per cent, and the thermal efficiency 16 or 17 per cent; showing, as we now well know, the extremely low efficiency ratios of low-pressure cylinders under condensing conditions.

These two efficiencies are the only ones of value in comparing steam results with internal-combustion-engine results. Messrs. Stott, Gorsuch and the writer have advocated, in a Prime Mover Committee report for the A.I.E.E., 1915, that the use of water rates be abandoned as not basic, and that the above efficiencies be substituted.

A. G. CHRISTIE (written). The paper gives some excellent data of the effect of superheat in a uniflow non-condensing engine. Considerable emphasis has been laid on the comparison of the uniflow and counterflow engines, and Fig. 14 shows comparative performance curves for several types of engines. It does not seem that any of these curves show compound condensing units with superheat.

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In large power plants there is a tendency to increase both steam pressures and superheat. The tests in this paper show the highly beneficial effect of adding superheat in a non-condensing unit. Engineers should therefore be interested in the performance of a small unit with high pressure, high superheat, reheating between cylinders, feedwater heating and condensing.

When the new laboratories of Johns Hopkins University were built, a 75-kw. Buckeyemobile was purchased from the Buckeye Engine Co. and direct-connected to a 50-kw. generator. This unit

TABLE 7 PART OF RESULTS OF TESTS ON 75-KW. BUCKEYEMOBILE [1]

Boiler pressure, gage, lb	212.4	212.5	213.4
Receiver pressure, gage, lb	0.33	9.65	22.6
Vacuum at exhaust, inches of mercury	27.28	26.88	26.32
Superheat entering h.-p. cylinder, deg. fahr	170.0	185.1	235.6
Superheat entering l.-p. cylinder, deg. fahr	117.3	130.2	126.7
Temperature of flue gases, deg. fahr	422	427	500
Calorific value of coal as fired, B.t.u. per lb	14,151	13,545	13,780
CO_2, per cent	12.38	13.82	13.34
Total i.hp. of engine	27.3	51.2	83.6
Total b.hp. of engine	23.3	47.4	73.2
Kw. output of generator	15.57	31.6	51.5
Revolutions per minute	247.7	247.6	247.7
Dry coal per i.hp-hr	2.32	1.57	1.40
Dry coal per kw-hr., lb	4.06	2.55	2.27
B.t.u. in coal consumed per kw-hr	57,453	34,540	31,280
Lb. of steam condensed per i.hp-hr	10.80	10.5	9.63
Lb. of steam condensed per b.hp-hr	12.65	11.32	11.0
Lb. of steam condensed per kw-hr	18.94	17.0	15.62
Efficiency ratio of engine based on indicated horsepower referred to adiabatic expansion, per cent	64.3	67.0	72.7
Efficiency of boiler alone, per cent	36.8	55.1	55.4
Efficiency of boiler, superheater, reheater and feedwater heater, per cent	43 2	64.6	66.3
Efficiency of complete plant from kilowatts at switchboard to heat in coal as fired, per cent	5.92	9.88	10.85

[1] Rated horsepower of unit, 75 i.hp. Cylinders, 6½ in. and 12½ in. in diameter by 15 in. stroke (tandem compound). Engine also drives a three-throw boiler-feed pump. Generator, 240-volt, 50-kw., direct-current, 3-wire.

had been used to carry the summer light and power load of the University, and for test purposes by the students during the winter months. A portion of the test results is given in Table 7, which results were obtained by members of the senior mechanical-engineering class in a series of tests made last winter. The unit was not prepared especially for test and was operated as in general service. It is felt that the results represent very closely average operating conditions, though other previous tests have indicated lower coal consumptions at the various loads.

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The unit has given very satisfactory service since it has been installed, and the operating and maintenance charges have been quite low. American engineers can well afford to give more attention to this type of unit with the rapidly increasing costs of fuel and labor.

THE AUTHOR. I agree with Professor Emswiler that it is often preferable to refer steam-consumption curves to b.hp. instead of i.hp. In the present case the difference in the form of the curves would be very slight, and it was decided to use i.hp. in view of the fact that it proved more difficult to find results of tests of engines, with which it was desired to make comparisons, expressed with reference to b.hp.

In answer to Mr. Adams's question, the heat value of the coal used was approximately 13,700 B.t.u. per lb., as fired.

In reply to Mr. Pigott's suggestion that the fact that the water rates are not in all cases lower, at all loads, with higher boiler pressure than with lower boiler pressure, indicates an error, and that the results might be adjusted with the aid of the Willans lines so as to eliminate this feature, I should like to call attention to the fact that if a Willans line is plotted for each boiler pressure of the saturated-steam runs, a very clearly defined tendency throughout for the higher-pressure lines to cross the lower-pressure ones at light loads will be evident. It is realized that the work doubtless contains some experimental errors, but it does not seem reasonable to infer that errors would occur in such a way as to indicate consistently the same thing. It does not therefore seem justifiable to adjust the results as suggested.

Moreover, it is evident that the cylinder condensation will be greater with high boiler pressures, due to the increased temperature ranges, than with lower ones. It does not seem unreasonable to infer that as the load becomes lighter and the cut-off earlier, a point will finally be reached where the loss due to increased cylinder condensation will overbalance the gain due to increased available energy, and the Willians lines cross, as actually indicated by the data presented.

I agree entirely with Mr. Pigott as to the value of the use of the thermal efficiency, B.t.u. per hour (or per minute), and the Rankine-cycle efficiency ratio, for comparison with other types of prime movers. The Rankine-cycle efficiency ratios referred to i.hp. will be found in column 12 of Table 2. The others are not presented in the paper.

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No. 1585

RELATION OF EFFICIENCY TO CAPACITY IN THE BOILER ROOM

By Victor B. Phillips, Cleveland, Ohio
Junior Member

By typical cost figures the author shows that 90 per cent of the cost of producing steam is for fuel and fixed charges (including labor). He states that these two charges are of almost equal importance, and that their reduction depends respectively on the attainment of efficiency and capacity. He then sets about to establish the procedure for determining the relation of maximum efficiency at various loads to those variables of operation which the fireman may observe and over which he must exercise control. Test data on a B. & W. boiler equipped with a Taylor stoker for a very wide range of operating conditions are used to illustrate the procedure and to show the validity of the selection of variables.

The data applying to the furnace and boiler are shown respectively in charts having efficiency and capacity as coördinates, and the interrelation of the operating variables is indicated, as on steam charts, by lines of constant values. These two charts are then combined into a single chart having as coördinates overall efficiency and capacity of the steam-generating plant, and which graphically represents the two objects to be sought — efficiency and capacity — in terms of the variables of operation through the manipulation of which they may be obtained.

The striking test results shown in the furnace operation chart are discussed in an appendix, which also gives details of the procedure employed.

THERE are two ways in which the cost of producing steam may be reduced. They are efficient operation and the attainment of high capacity from equipment. Table 1 gives typical figures for the various elements of cost entering into the production of steam, according to the accounts of the Cleveland Railway Company for the year 1914. The numbers shown in parentheses refer to the accounting system prescribed by the Interstate Commerce Commission. This table shows the predominating importance of fuel and fixed charges, and hence the importance of both efficiency and capacity and their interrelation.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of The American Society of Mechanical Engineers.

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2 To the end of establishing the operating conditions giving maximum efficiency for a wide range of capacities, the writer has made an extensive series of tests for the Cleveland Railway Company. The tests were conducted under widely different operating conditions in order to bring out clearly the importance of the several variables and also to throw light on questions of design. In Table 2 is a condensed summary of the data obtained, together with some notes as to procedure.

TABLE 1 COST FACTORS IN STEAM PRODUCTION

CLEVELAND RAILWAY COMPANY

		Per cent of total cost	
1 (53)	Fuel	50.1	50.1
2 (54)	Water	3.4	.....
3 (55 & 56)	Oil and miscellaneous supplies	0.4	.....
4 (46 & 47-A & B)	Maintenance	6.4	.....
5 (52-A)	Employees	9.6	9.6
6 (50)	Depreciation, 4½ per cent on investment	11.3	11.3
To these must be added interest, taxes and insurance, 7½ per cent on investment		18.8	18.8
Total cost of producing steam		100.0	
Fuel and fixed charges		.....	89.8

GENERAL DESCRIPTION OF TESTS

Equipment (see Fig. 1). Taylor six-retort stoker with extension grate. Babcock & Wilcox boiler, 5120 sq. ft. heating surface.

Duration. Eight hours, preceded by preliminary run under test conditions; setting under heat for several days before tests, except for Tests 7 and 8, which therefore show small discrepancies when referred to boiler operation chart. Readings taken every 15 min.

Personnel. In addition to regular operating fireman and helpers, personnel included six men all of whom had become thoroughly familiar with their duties through previous tests.

Coal and Water. Both items were weighed on newly calibrated scales. Coal sample taken from every wheelbarrow and placed in covered receptacle.

Air Supply. Air delivered to furnace from fan was measured by pitot tubes placed in air ducts and preceded by baffles to create parallel flow; permanently located pitot tubes were calibrated by complete traverses in two directions through the pipe and results checked with an anemometer and by the calorimetric method. Pressure and draft gages checked.

Temperatures. Obtained by thermoelectric pyrometers, checked by manufacturer before and after tests.

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Gas Analysis. Conducted by chemist. Continuous samples taken during consecutive half-hour periods. Sampling tube inserted at top of first pass; lined with hard glass tubing and open at end only; moved in and out so as to get representative sample. Analysis made with Orsat apparatus.

Regulation of Fire. Fuel bed was kept uniform and constant in thickness, by very close and frequent observation on the part of three different men, all experienced firemen.

Ash Analysis. All ash was spread out and crushed to about 1½ in. on a large concrete floor and dried before weighing. The sample for analysis was taken by dividing the ash when evenly spread out, into a

TABLE 2 SUMMARY OF TEST DATA

CLEVELAND RAILWAY COMPANY

Test No.	1	2	3	4	5	6	7	8	9
1 Fuel-bed thickness	Thin			Medium			Thick		
2 Horsepower output of boiler (steam pressure 150 lb. gage)	452	661	895	500	736	923	504	718	902
3 Dry coal per hour, lb.	1,695	2,450	3,700	1,960	3,100	4,000	2,690	3,600	4,320
4 Coal analysis:									
a B.t.u.	12,631	12,718	12,744	12,795	12,888	12,944	12,802	12,802	12,672
b sulphur, per cent	4.00	4.00	4.00	4.00	4.00	4.00	4.16	4.16	3.93
c ash, per cent	13.2	12.4	12.6	12.4	11.8	11.6	12.5	12.5	13.2
5 Air pressure under tuyeres (inches of water)	0.46	1.33	2.63	0.55	1.68	2.79	1.03	2.41	3.27
6 Draft in combustion chamber (inches of water)	0.22	0.25	0.25	0.25	0.27	0.41	0.15	0.15	0.45
7 Pounds air per hour by meter	20,100	30,900	42,600	15,700	30,200	46,500	20,900	37,200	43,500
8 Average of air by meter and by analysis, lb. per hr.	25,200	32,000	38,500	17,850	30,300	40,250	21,900	34,250[2]	42,250
9 Temperature of air, deg. fahr.	66	66	68	66	69	70	79	80	72
10 Temperature in last pass	532	644	734	500	659	771	509	596	728
11 Sensible heat to stack, per cent[1]	14.5	17.0	14.6	8.4	12.1	14.7	7.6	10.4	13.7
12 Combustible in ash, per cent loss[2]	5.1	4.0	7.6	4.6	10.0	7.0	17.3	17.3	20.0
13 CO loss[3]	0.4	0.8	10.9	6.6	11.2	13.9	14.8	11.4	.....
14 Latent heat of steam in flue gas	3.5	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.7
15 Overall efficiency, per cent	70.7	71.2	63.5	66.9	61.7	59.7	49.0	52.1	54.8
16 Furnace efficiency, per cent	85.2	88.2	78.0	75.3	73.8	74.4	56.5	62.5	68.5
17 Output of furnace, boiler hp.	544	820	1,100	563	880	1,150	583	862	1,127

[1] Flue gas per pound of coal, taken from items 3 and 8, to which is added 0.8 pound for gasified coal.

[2] One sample for Tests 7 and 8.

[3] The CO analyses, especially for the overload tests (Nos. 3, 6 and 9), were probably somewhat in error due to taking of sample at top of first pass where gases were not thoroughly mixed. During Test 9 both the oxygen and CO content of the flue gas taken at this same point were high. There was also a marked amount of incandescent matter in the flue gas. It is therefore probable that considerable combustion of CO occurred in the second and last passes. This is indicated by the fact that the items of the heat balance for this Test 9 added up to a little more than 100 per cent.

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large number of squares, and then moving away alternate squares until a comparatively small sample for grinding was obtained. Dur-

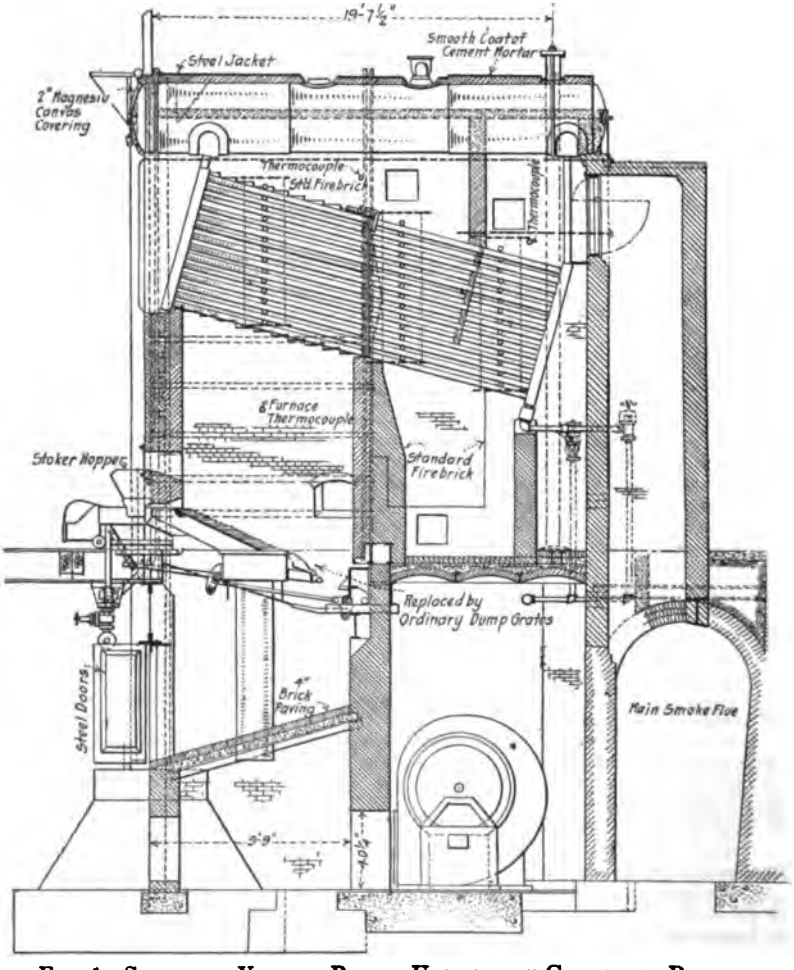

FIG. 1 SECTIONAL VIEW OF BOILER UNIT OF THE CLEVELAND RAILWAY COMPANY

ing this reduction process the ash was continually mixed by turning it over. The samples were analyzed for moisture, combustible and in some cases for sulphur or volatile constituent.

SCOPE OF PAPER

4 This paper proposes for discussion the systematic treatment of the steam boiler in relation to the two fundamental variables —

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efficiency and capacity. The efficiency which obtains at a given capacity depends upon the interrelation of a large number of variable factors of operation. It is essential that these factors be systematically conceived and that in a given case some idea of their relative importance be formed. Recent stoker developments to the end of greater flexibility have introduced a large number of adjustments over which intelligent control must be exercised. This merely goes to illustrate the necessity of less prejudice and more rational procedure in boiler-room design and operation.

5 In what follows, a classification of the variables of operation will be outlined, and a system of testing discussed, whereby their interrelation may be established. The results of the tests already quoted, which were made in accordance with this system, will be used by way of illustration. All mathematical treatment and detail of procedure are listed in the Appendix. It should be pointed out at the outset that the test data used are necessarily limited and in some respects incomplete. Yet perhaps they will serve as a concrete basis or example in outlining the method of treatment.

ELEMENTS OF BOILER UNIT AND BASIC FACTORS WHICH GOVERN ITS PERFORMANCE

6 The steam-boiler unit is considered here in relation to each of its two elements, the *furnace*, or heat liberator, and the *boiler*, or heat absorber.

7 The furnace is a means whereby the chemical energy of coal or other fuel is transformed into sensible-heat energy. The function of the furnace is chemical reaction between the combustible fuel and the oxygen of air. As such, it is governed by the three factors, (1) amount of air, (2) degree of air mixture and (3) time. These three factors together govern the rate of combustion, the completeness of combustion and the resultant temperature of combustion; in a word, they completely determine the nature of combustion.

8 The boiler is a means whereby the heat liberated in the furnace is absorbed and transferred to the water. Its function is heat transmission and it is governed by the laws expressing the several modes of heat transmission — conduction, convection and radiation. It is evident that the factors which govern combustion likewise govern very largely the heat transmission of the boiler, by the regulation of temperature and amounts of gas. Hence, it follows that in the end the performance of the entire boiler unit may be expressed in

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terms of a number of factors over which the fireman either does or should be able to exercise proper control.

9 Before proceeding with the separate discussions of the two elements of the boiler unit, it is necessary to define clearly the lines of separation of the furnace and the boiler. It is desirable so to define furnace efficiency and boiler efficiency that their product will be the overall efficiency of the unit.[1] To this end boiler efficiency is taken as the ratio of heat absorbed to the heat available for absorption, i.e.,

$$E_B = \frac{\text{heat in the steam}}{\text{heat in steam and sensible heat in flue gas}}$$

Furnace efficiency is defined as the ratio of heat available for absorption by the boiler to the heat in the coal, i.e.,

$$E_F = \frac{\text{heat in steam and sensible heat in flue gas}}{\text{heat in coal}}$$

and

$$E \text{ (overall efficiency)} = E_F \times E_B$$

10 This method arbitrarily charges against the furnace all losses through the setting, such as radiation and leakage. Most of these losses do occur in the setting around the furnace and so this arbitrary classification is reasonable. It also charges against the furnace the loss in latent heat in the vapor of the discharged flue gases.

THE FURNACE

11 The ideal furnace for any form of fuel is one in which the three factors of combustion mentioned above — amount and admixture of air, and time for completion of combustion, may be regulated independently. This furnace would have wide limits of efficient operation wherein it would be possible to attain at once both efficiency and capacity. Unfortunately, the present status of the art, particularly in regard to coal-burning furnaces, falls far below this ideal.

12 The most important methods of firing coal employ the chain grate and the underfeed and overfeed gravity stokers. In each of these cases the time of transit of coal decreases with increase of load and is not subject to independent regulation, and also it is impossible to regulate independently the amount and admixture of air. The factors of air supply are controlled together, by the amount of draft or

[1] The definitions here used have been drawn so as to simplify the analysis. They offer no radical change over similar definitions and, while open to some objections, are simple and easily understood.

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pressure and by the condition of the fuel bed. These several inflexibilities are inherent in the present status of the art. They are serious disadvantages which may be reduced, however, by introducing in other ways a large degree of flexibility.

13 Since regulation of the time element by regulation of grate surface seems to be impracticable, the problem of furnace operation becomes simply the *problem of the air supply*, not merely over the fuel bed as a whole but in its several parts separately. That flexibility of air supply will to some extent compensate for inflexibility in time of transit, may be illustrated by any of the underfeed gravity stokers. The grate areas of these stokers have been proportioned to give the proper time element for rated capacity.

14 For example, take the case of the Taylor stoker used in the equipment of the Cleveland Railway Company's plant which the writer tested. When the capacity is increased, the air supply on the lower or coking grates cannot be increased enough to burn the coal as fast as it is received from the upper grates. The result is a piling up of coke and ash on the dump and extension grates, causing not only a large loss from carbon monoxide and coke to the ashpit, but perhaps serious clinker difficulties. A variable grate surface would eliminate this trouble. It could, however, be largely mitigated by flexible and independent air control for this section of the fuel bed. This is discussed further in the Appendix.

FUNDAMENTAL FACTORS OF OPERATION OF THE FURNACE

15 The operating variables of the furnace are simply the variables governing air supply. They are (1) thickness of fuel bed, (2) condition of fuel bed, and (3) pressure drop through fuel bed. These variables may be regulated differently in different parts of the furnace, but they are in all events the fundamental factors involved. They determine efficiency and capacity. In order to operate a furnace properly, the interrelations between efficiency and capacity and the foregoing variables must be established.

16 The validity of this principle has not been generally realized. Instruments for the indication of certain variables have been extensively used. Yet either the number of instruments or the amount of rational interpretation has been insufficient. It is only in very special and limited cases that efficiency or capacity is indicated by a single variable factor such as carbon dioxide, or flue temperature.

17 Having defined the fundamental factors of operation, it now remains to select means of indicating these quantities to the fireman.

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The means of indication necessarily vary for different types of stokers and furnaces. With a chain grate the thickness of fuel bed may be readily measured and adjusted, and its condition is for the most part uniform. The draft in the combustion chamber constitutes the pressure drop through the fuel bed. Thus the chain grate readily lends itself to this system, and it is a simple matter to determine by tests the relation of furnace efficiency and capacity to the operating variables. In fact, the limits of expedient and efficient operation with the chain grate are not only narrow but readily apparent. This is a salient feature of this type of stoker. On the other hand, the

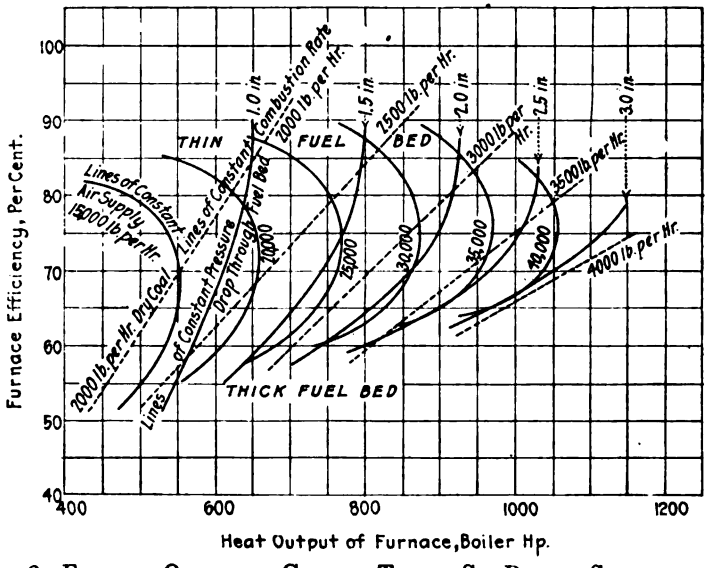

FIG. 2 FURNACE OPERATION CHART. TAYLOR SIX-RETORT STOKER WITH EXTENSION GRATE

forced-draft underfeed stoker is not by any means so simple, and here intelligent control is not only effective but essential. In this case the thickness of fuel bed cannot be *directly* measured, nor is its uniformity so much a matter of course.

18 The point of primary importance is the amount of air pushed through the fuel bed and the intimacy with which it is mixed with the volatile matter forming in the lower layers of green coal and the coke of the upper layers. Roughly speaking, this intimacy increases with the resistance to air flow. It is the condition and thickness of the fuel bed that determines both the amount and admixture of air. The pressure necessary to force up a certain quantity of air is both a

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simple and an effective indication of the mean condition and thickness of the fuel bed; in other words, an air-pressure gage and an air meter indicate the thickness of bed. In stokers of sufficient size to warrant the use of two air ducts, it is necessary to duplicate the air-measuring apparatus. By proper arrangement of the means of indication it now becomes possible to gage the uniformity of the fuel bed by comparing the air indications to the two halves. Thus all the conditions

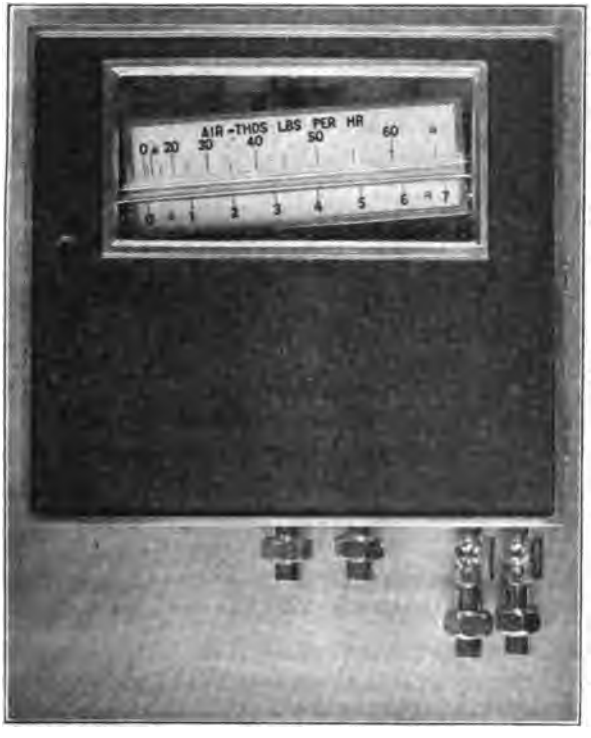

FIG. 3 AIR METER

governing air supply may be readily measured and indicated to the fireman. In order that he may make proper use of these indications, they must be related to the objects sought — efficiency and capacity.

19 As an illustration of the actual interrelating of the above indications, there is presented in Fig. 2 a chart showing graphically the results of the tests applying to the furnace.

20 It may be seen that this chart is a graphical representation of the principles outlined above. It shows how furnace capacity

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and efficiency are functions of extremely simple variables, and how any two of the variables fix conditions of operation. An analogy is a steam chart on which any two conditions such as heat and pressure, or quality and temperature, determine a point from which the other corresponding conditions may be found. The chart brings out in conclusive manner the essential importance of the variables selected at the beginning of the discussion — thickness of fuel bed and pressure drop. So far as the furnace as a heat liberator is concerned, it establishes the conditions of maximum efficiency for each and every load.

MEASUREMENT OF AIR SUPPLY

21 Of the instruments used by the writer in obtaining the results presented here, the apparatus for directly measuring the air supply,

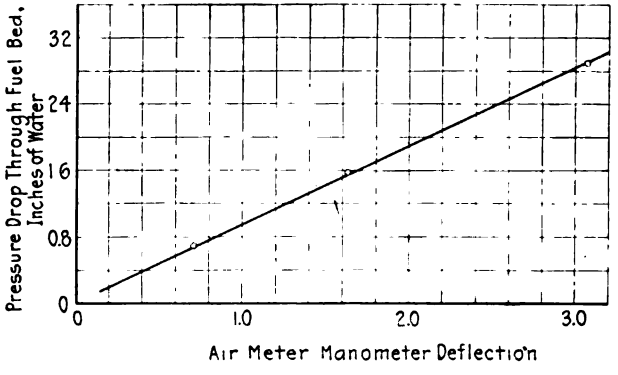

FIG. 4 RELATION BETWEEN PRESSURE DROP THROUGH FUEL BED AND AIR-METER MANOMETER DEFLECTION, FUEL BED OF CONSTANT THICKNESS

Fig. 3, merits perhaps a brief statement. It is quite possible to employ the pitot tube with close accuracy for measuring the air supply of forced-draft furnaces and, even where conditions are extremely unfavorable, to obtain at least excellent relative results. The manometer used in connection with the pitot tube may be placed at a distance from the air duct, along with the other boiler instruments, without impairing its accuracy. When two manometers are necessary because of two air ducts the sloping tubes may be placed side by side and readings taken from a single scale. The only time that the liquid levels will not be side by side will be when the fuel bed is not uniform, a condition requiring immediate attention from the fireman. For example, a hole will cause a very marked difference in the two manometer levels.

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22 Another principle may be employed in connection with the form of air meter just described. The pitot-tube manometers show deflections increasing as the square of the air velocities. Similarly, neglecting the relatively small amount of gas formed from the burning coal, the pressure drop through the fuel bed varies as the square of the air velocities. Hence, as is shown in Fig. 4, the relation between this pressure drop and the manometer deflection is a direct proportion. Utilizing this principle, another manometer tube[1] may be placed beside the other tubes for the measurement of pressure drop. By using liquids of the proper relative densities, or by introducing variation in the sectional area of the manometer, the levels can be set to move up and down together for the proper thickness of fuel bed; and a ready indication of amount of variation from the prescribed thickness is available. This last function is valuable in plants having short peak loads. The fireman may gage the amount by which he is building up his fuel preparatory to the short overload. Thus a single instrument has been made to indicate all the fundamental conditions of combustion — amount of air, pressure drop through the fuel bed, and thickness and uniformity of fuel bed.

THE BOILER

23 The performance of the boiler as an apparatus for absorbing heat may be analyzed along the same general lines as the furnace. The furnace produces heat which is available for absorption in the form of radiant energy and of hot gases, that is, the heat generated in the incandescent fuel bed is transmitted to the boiler surfaces by radiation and by convection. It is then transmitted from the outer to the inner surfaces and to the water by conduction. The boiler employs, therefore, all three modes of heat transmission, and the variables of operation are those determining the effectiveness of each of these three modes. These variables are (1) temperature, (2) condition of surfaces, and (3) gas velocity. Temperature is the predominant variable; it affects all three modes of transfer, in each case a temperature gradient being necessary. The condition of surfaces affects principally two modes of transmission, convection and conduction; while gas velocity affects simply convection.

24 The researches of Messrs. Kreisinger and Ray, of the U. S. Bureau of Mines, have shown that of the total temperature difference between the hot gases and the boiler water the drop through the solid material is only a small part. The principal drop is through

[1] Not shown in Fig. 3, but exactly similar to the two tubes shown.

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the gas film which adheres to the boiler surfaces. Since the thickness of this film for a particular condition of the boiler surfaces is governed by the conditions of gas flow, the drop through it should be classed as part of the convection process.

25 The relatively small temperature drop through the solid material also serves to explain the matter of soot and scale. Within the limits set by good practice, variation in soot and scale does not seriously affect boiler performance. For this reason, tube condition as a variable of operation will not be treated. Furthermore, inasmuch as conduction is a supplementary process of heat transfer and is governed by the variables of radiation and convection, the heat absorbed by a boiler may be divided logically into two items — the heat absorbed by radiation and the heat absorbed by convection.

26 It is obviously impossible to separate sharply radiation and convection. Heat is transferred by radiation in all parts of the boiler and the same holds true of convection. However, the theoretical laws expressing these modes of transfer create a working distinction. The heat transmitted from a hot to a cold body by radiation increases much more rapidly with temperature difference than the heat transmitted by convection. For ideal conditions radiation increases as the difference of the fourth powers of the two temperatures. Convection heat increases directly with temperature difference. From this it is apparent that heat is transmitted to the boiler by radiation very much more rapidly in the regions of high temperature. Radiation will become the preponderant means of heat transfer as the temperature increases; while convection becomes relatively more important at low temperatures.

INFLUENCE OF RADIATION AND CONVECTION

27 The curves in Fig. 5 illustrate the parts played in a boiler by radiation and convection. The upper curve shows actual temperatures along the path of gas travel. The lower curve shows the temperatures for the same conditions of loading, as calculated from the convection constants for the second and last passes. These constants were determined from observations made only at the top of the first pass and the end of the last pass.[1] Hence the intervening temperatures shown by the lower curve correspond to strictly theoretical convection. It will be noticed that in the second half of the boiler actual conditions of heat transfer conform closely to those of pure convection. As the regions of maximum temperature are ap-

[1] For complete data on methods of procedure, see Appendix.

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proached the actual curve diverges more and more, due to some factor not accounted for by the laws of convection. This factor is radiation.

28 By reason of a number of conditions, radiation is an important mode of heat transmission through a large part of the boiler. For water-tube boilers there are lanes through which the radiant energy of the fuel bed and furnace walls has direct ingress to remote tubes. In all boilers the gases remain to some extent incandescent through a considerable part of the path of travel. This may be due to suspended matter or to belated combustion. Furthermore, boiler sur-

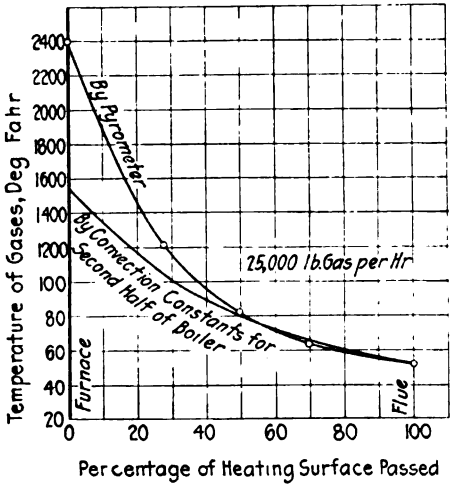

FIG. 5 TEMPERATURE DROP THROUGH BOILER SETTING

faces will have slight protruding irregularities, especially in the way of foreign matter. These irregularities will become heated to incandescence and thus radiate heat to surrounding surfaces independently of the gas films which so seriously hinder convection.

29 The relative importance of the two modes of heat transmission —radiation and convection — has been indicated by the foregoing. It now remains to present a means whereby the two components of the heat absorbed may be separated for further investigation. The increased temperature gradient produced in the first pass by reason of radiation also serves to modify the process of convection. In considering the above curves it is evident that more heat will be absorbed by true convection than the convection relation determined

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from the last two passes would show; this because the higher temperatures cause a greater flow of heat from gas to water.

30 In view of the difficulties incident to studying convection in the regions of very high temperatures, the following arbitrary method of dividing the heat is presented. The convection relations are determined for the last two or three passes in the path of gas travel, depending upon the type of boiler. These constants are then assumed for the entire boiler and the heat absorbed, as calculated on this basis, is called the heat from convection. The difference

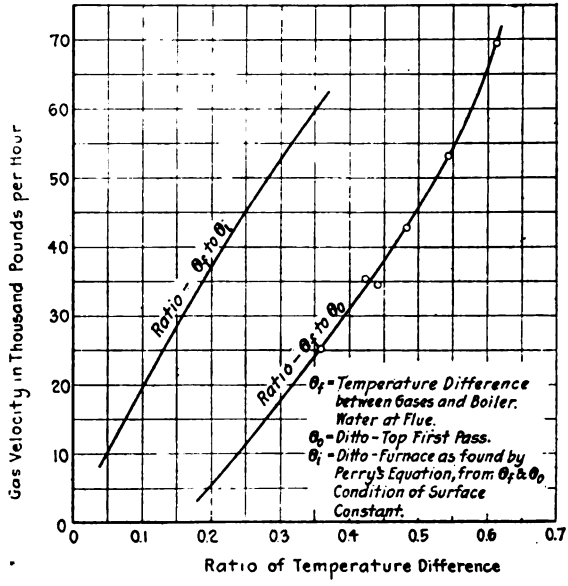

FIG. 6 CONVECTION RELATIONS OF BOILER

between this convection item and the total heat absorbed is called the heat from radiation. The fault with this plan is the inclusion of some convection heat under the head of radiation. Whether or not this is a serious fault will be brought out by a concrete example.

31 It has been said that radiation is a function of the one variable — temperature. Because of the wide temperature range in the zone where radiation is active, it is desirable to select a mean temperature in terms of which total radiant heat may be expressed. In the present example the initial or furnace temperature (T_i), found by the convection equation, is used. This temperature is very nearly equal to the mean effective temperature in the first pass and is therefore

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an excellent indication of the range of temperatures which determine radiation heat.

32 The validity of the plan presented here is now shown. Heat from radiation found, as explained above, by the method of difference is plotted (Fig. 7) against the initial temperature taken from the convection chart, Fig. 6, expressed in degrees absolute. The result is a logarithmic curve the exponent of which is 3.4, whereas the exponent for theoretically ideal conditions is 4.0. This indicates that the heat values plotted are almost entirely heat from radiation and that the foregoing hypotheses are sound.

BOILER OPERATION CHART

33 The relations just derived between the heat absorbed by the boiler and the two variables — *flue temperature* and *gas velocity*, may

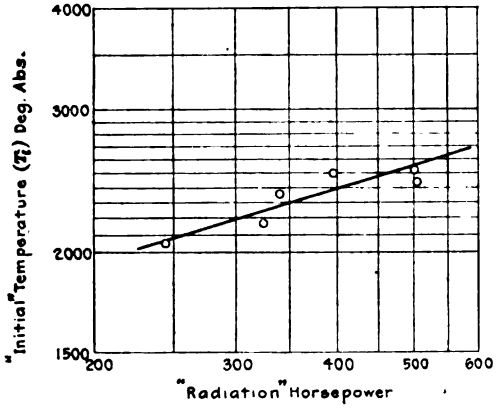

FIG. 7 HEAT FROM RADIATION PLOTTED AGAINST INITIAL TEMPERATURE

be combined into a single chart. This chart, Fig. 8, is the boiler operation chart, and corresponds to the furnace operation chart previously shown. It expresses the relation of efficiency and capacity to the fundamental factors — temperature and velocity of the gases. In working out this particular example no account has been taken of the only other operation variable — *condition of the heating surfaces*. A complete treatment should include this condition as a variable factor. To do this requires simply a redetermination of convection and radiation constants for each of several degrees of soot and scale.

34 The foregoing method of boiler analysis is valuable, not merely as a guide to operation, but also as a means of studying de-

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sign. For example, it serves to explain a number of tendencies in recent practice. The boiler settings used by the Detroit Edison Company emphasize the predominance of radiation in the first bank of tubes, first, by the direct exposure of surface to the radiant heat, and second, by keeping the gas velocity low. On the other hand, convection is improved in the second and third passes by increasing the velocity in this region.

COMBINED BOILER-UNIT OPERATION CHART

35 Having treated separately the two elements of the boiler unit — the furnace as a heat liberator and the boiler as a heat absorber,

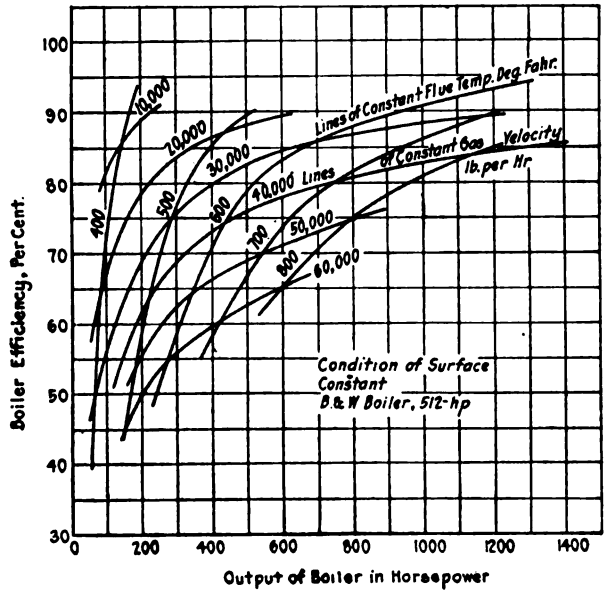

FIG. 8 THE BOILER AS A HEAT ABSORBER. BOILER OPERATION CHART SHOWING INTERRELATION OF VARIABLES

it remains to combine the results of the two analyses. As an example of such procedure there is presented in Fig. 9 the combined boiler-unit operation chart.

36 It is evident that the factors governing furnace operation also determine the variables of boiler operation. The gas passing through the boiler is simply the air of combustion plus the weight of gasified coal (corrected, if necessary, for infiltration). The temperatures in the boiler are governed by the combustion conditions in the

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furnace. Hence, overall boiler efficiency and capacity are to be expressed simply in terms of the furnace variables — *thickness of fuel bed* and *pressure drop through fuel bed.* In the case presented here fuel-bed thickness is indicated by weight of air and pressure drop, and these values therefore become the criteria of combined performance. The function of flue temperature is simply a check upon the condition of the heating surfaces. The combustion-rate

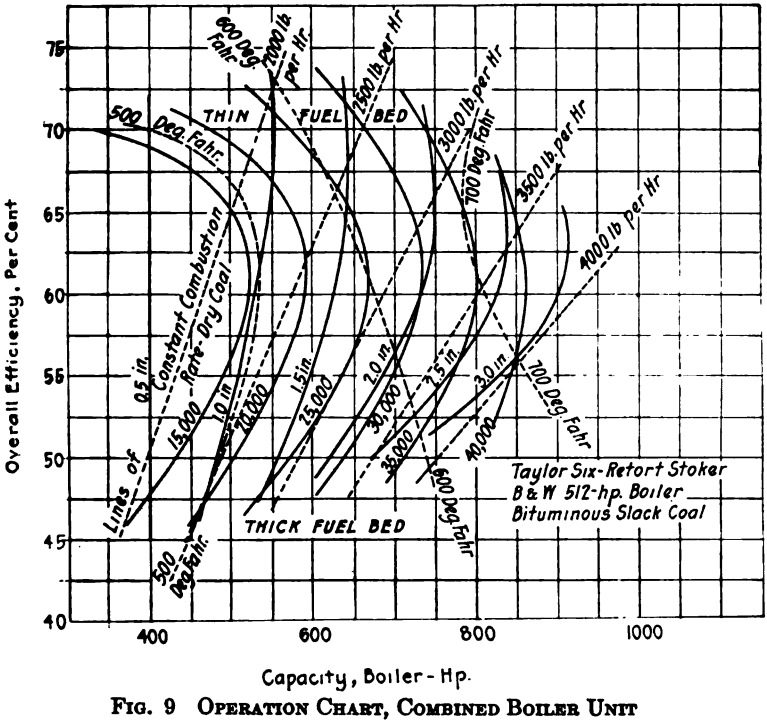

FIG. 9 OPERATION CHART, COMBINED BOILER UNIT

curves shown on the chart are of value only in assisting in the proper maintenance of fuel bed. However, this information is not necessary since an insufficient fuel supply shortly disturbs the prescribed relation between air and pressure drop. Reference to the data shows very little variation in the character of coal used in the tests the results of which have been presented. This condition is indispensable under such a system of testing and can be attained easily by using coal from a pre-mixed source of supply. Once the desired relations have been established for an average and uniform grade of coal, the value of the results is not impaired by reasonable variation from such

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grade. Boiler performance will change, but the interrelation of variables over which the fireman exercises control should not change appreciably. It would be only a radical variation in size or quality of coal that would necessitate a change in fuel-bed thickness in order to maintain maximum efficiency. The real objective is the best performance for each load for the grade of coal available. More than this can be claimed by no system of operation or class of design.

37 The combined boiler-unit operation chart brings out the essential importance of the variable factors which have been selected as determining performance. It supplies the information whereby the firemen may operate with maximum efficiency for each different load. It establishes the relation between efficiency and economy wherewith the economic policy of the boiler room may be rationally planned. Lastly, a study of the chart and of the reasons for its characteristics becomes a sound basis for improvement in design.

38 In conclusion, the writer wishes to state clearly his position. It is not an unqualified acceptance of any single system of analysis, but rather the acceptance of the *principle* of systematic analysis. There is no engineering problem which is immune to this principle.

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APPENDIX

(A) PROCEDURE FOR CONVECTION TESTS

39 Perry's equation,

$$\theta = \theta_0 e^{\frac{-Cx}{c + KW}}$$

is used in the determination of convection heat.

θ_0 = initial temperature difference between hot gas and boiler water

θ = temperature difference between gas and water at distance x from starting point

W = weight of flue gas per unit time

c = tube conductivity

e = Napierian base

C and K are constants depending upon the units in which θ, W and c are measured and upon the nature of the surfaces, path of travel, etc.

40 The equation may be changed to the form

$$2.3 \log_{10} \frac{\theta}{\theta_0} = \frac{-Cx}{c + KW}$$

which shows that the logarithm of θ/θ_0 varies directly as the length of path of gas travel; and that θ/θ_0 for a single value of x is a logarithmic function of W. The problem here has been to determine this function.

41 It is obviously impractical to determine the value of W for each space increment from the walls to the center of the setting, and it is desirable for several reasons to consider W simply as the total weight of gas, measured in pounds per hour. This W, weight of gas, is distributed across the setting with different velocities in the different space increments. Hence, it is necessary to determine *mean effective temperature* differences as the values of θ and θ_0. In other words, θ and θ_0 are in terms of average temperatures, weighted with regard to gas velocity and density. Their determination therefore required traverses across the setting for both temperature and velocity.

42 By means of a special form of pitot tube and a bare thermocouple of small mass a large number of traverses were taken. These traverses were taken at two points — the top of the first pass and the top of the last pass, where it was possible to place the couple and pitot tube well away from the boiler tubes. It was found that variation in temperature across the setting was negligible in the last pass, so that here velocity traverses were unnecessary. In the first pass, however, the temperature varied considerably. At this point the gases are frequently incandescent, thus permitting direct observation of the stream lines of flow. From this the pitot tube was set with its axis properly directed. Two complete sets of traverses were taken for each of five different conditions of boiler loading. A set of traverses comprised readings for temperature and velocity at five equally spaced points from the wall to the center of the setting, repeated in rapid succession at least five times and twice that number if variation for a single point was appreciable.

43 The results of these tests have been presented graphically and show the desired relation between θ/θ_0 and W. In accordance with the above the

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ratio of temperature differences may be calculated for the entire path of gas travel and *convection horsepower* expressed in terms of the variables flue temperature and weight of gas.

(*B*) DETERMINATION OF RADIATION HEAT

44 The data given in Table 2 of the paper afford simultaneous averages for the following:

a Total heat absorbed per hour, boiler hp.
b Total weight of gas passing through boiler, lb. per hr.
c Temperature of escaping gases, deg. fahr.

The last two values when applied to the convection curves determine *convection heat* (so-called), and also the value *initial temperature* previously referred to. By difference, the item *radiation heat* is found. It has been shown already that radiation heat is a logarithmic function of initial temperature and may be expressed by

$$H_R = CT_i^{3.4}$$

where H_R is in boiler horsepower and T_i in degrees absolute.

45 The theoretical law, Stefan's law of radiation, is expressed

$$H_R = C\,(T^4 - t^4)$$

where T and t are the temperatures in degrees absolute of the hot and cold bodies respectively. This law is for the ideal case of black bodies where the bodies *see* each other completely. It is evident that if T is much larger than t the item t^4 may be dropped from Stefan's equation, leaving

$$H_R = CT^4$$

This expression is similar to the one derived for the boiler. The difference between the exponents 4.0 and 3.4 may be readily accounted for by the practical variation from ideal conditions and by the small item of convection heat arbitrarily included in H_R.

46 It has been pointed out above that one reason for radiation being active throughout the boiler is the incandescence produced by suspended particles of ash and coke. During Tests 7, 8 and 9 (Table 1) such incandescence was very marked — much more so than during the other tests. As a result the radiation heat for these three tests is considerably higher for the same temperatures. The data for Tests 7 to 9 have not been plotted on the radiation curve sheet because they are not comparable. The points for these tests lie approximately on a straight line displaced to the right.

(*C*) DISCUSSION OF FURNACE AND STOKER CHARACTERISTICS

47 The furnace characteristic data and curves which have been presented are primarily for the purpose of practical illustration in developing a theory of control. They are the characteristics of one particular stoker and furnace setting (the Taylor stoker and the setting shown in Fig. 1). It has been pointed out that a study of such characteristics should bring out weaknesses and possible improvements in design. This is strikingly true in the present instance. Hence, further discussion of the furnace data is perhaps of interest.

48 It will be noticed that the effect of fuel-bed thickness upon furnace

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efficiency is most marked for the light loads and least marked for the heavy loads. With a thin fuel bed a drop in efficiency characterizes heavy overloading. With heavy fuel bed the reverse is true. The explanation of all this lies primarily in the air supply and distribution.

49 The data are self-evident in showing an insufficiency of air for all loads in the case of the heavy fuel bed. Obviously, at light loads the thick bed shuts off the air most effectively. However, the key to these peculiar characteristics is to be found in the air supply to the lower extension and dump grates. Quite regardless of the fuel-bed thickness, overloading is accompanied by a piling up of unburned coke on these grates. The grates are designed for rated load, and for rated load the air supply is sufficient. The extension grates are supplied with air from a chamber opening through slide valves into the main-grate air boxes. Hence, any regulation of the main air supply affects proportionally the extension-grate air supply.

50 The stoker also depends to some extent on the air drawn up through the dump grates by the small draft carried in the furnace. When the boiler is overloaded it becomes necessary to increase proportionately the combustion rates and therefore the air supply on all sections of the grate surface. This applies just as much to the extension and dump grates as to the main grates. However, due to both an insufficient and an almost inflexible air supply on these lower grates, combustible is delivered from the upper or main grates much faster than it can be burned on the lower grates. The result has been indicated. The piling up of ash and combustible rapidly makes worse the insufficiency of air. The losses from CO and the combustible to the ashpit increase excessively, and the net results are low efficiency and a tendency to the formation of clinker. The gas-analysis charts show that almost all the CO is formed on these lower grates. The CO begins at a low value just after cleaning and increases as the piling up of combustible increases.

DISCUSSION

WILLIAM KENT said that about twenty-five years ago he had stated before the Society that the relation of the efficiency of a boiler to its capacity was not expressed by any curve or formula, but by a field the upper limit of which represented the results that could be obtained under the best possible conditions. The width of this field was very great and was a measure of our ignorance concerning how to get the best conditions.

His studies for forty years had been directed toward helping to narrow the limits of this field, which had now been done to the extent that the action of a boiler could be predicted to within 5 per cent or less when the conditions as to quality of fuel, air supply and rate of driving were known.

In regard to the thickness of the fire, some thirty years ago he had made a 24-hr. test with pea and dust coal and with every facility for making good observations. The test was divided into 8-hr.

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periods and the first period was run with thin fires, the second with medium fires, and the third with thick fires. The best results were obtained with thin fires and with thick fires, and the worst with medium fires. From these data he did not think anyone could draw any conclusion.

In 1896 he had made a series of 75 tests on a Babcock & Wilcox boiler with a great many variable conditions. Some of these tests run with thick fires and strong draft gave results within 1½ per cent of those obtained with thin fires and moderate draft, again leading to no conclusion as to the merits of thin fires and thick fires except that when the thickness of the fire is properly regulated with reference to the draft then equally good results may be obtained with either a thin or a thick fire.

In regard to carbon monoxide, he had a series of collecting bottles arranged so that gas samples could be taken from a point halfway through the boiler tubes every minute. The first minute gave no oxygen and 7 per cent CO_2; the second minute 4 per cent CO_2 and a trace of oxygen, and at the end of five minutes there was 7 per cent free oxygen and no carbon monoxide. This showed the tremendous variation in conditions that could exist inside of five minutes.

This test led to no conclusion as to the CO_2 except that it was extremely variable. Results of 75 tests were plotted against every variable, and such conclusions drawn as could be.

What conclusions he had obtained in nearly forty years of making boiler tests were to be found in his Steam Boiler Economy. A little differential calculus had been used in dealing with the problem, but the results have now been reduced to simple straight-line formulæ and diagrams. He hoped Mr. Phillips would check his results against those given in that work and see if he could not reach more definite conclusions than those given in the paper.

L. C. Bowes thought the paper pointed out one very essential thing: namely, that the results given in Fig. 9, as he interpreted them, showed that the maximum efficiency was gained at about 25 per cent overload. There seemed to be a great tendency at present for stoker manufacturers to recommend stokers to fire above the rated capacity of the boiler, for which tendency central-station practice had probably been responsible.

With a stoker and boiler giving a high overload capacity, with a 12-hr. peak, the loss in the boiler due to high overload capacity,

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in order to operate the stoker at an efficient point, would exceed the loss due to maintenance charges on additional boiler capacity with stokers somewhere near consistent with the rating of the boiler. This point was very essential where there was a standing load on a 10-, 12- or 24-hr. peak.

In central-station practice, where there was only a three- or four- or sometimes a single-hour peak, high overload capacity of course was required, but he would like to see some curves showing in some way the relation between the fixed charges and fuel cost dependent on varying relations between the stoker capacity and the boiler capacity.

W. F. M. Goss. In our efforts to increase efficiency we are likely to lose sight of a matter of considerable present-day importance to which mechanical engineers should give due attention: when boilers are driven to higher capacities, an increase in the pollution of the atmosphere results.

The record of locomotive-boiler performance in this respect has long since been defined. We know that as we increase the capacity of a locomotive boiler we also increase the percentage of solid fuel passing up the stack. The exact relation between solids (fuel and ash) passing up the stack and rates of combustion for a considerable number of different fuels is known for locomotives from which a third and sometimes a half horsepower is secured per square foot of heating surface. There is very little similar information concerning the behavior of boilers in stationary power plants, notwithstanding the fact that we are constantly increasing the rates of combustion in such plants, and by so doing are bringing stationary practice to a point where it overlaps a portion of the field covered by locomotive service.

Mechanical engineers are naturally interested in the relation of boiler capacity to boiler efficiency; my present purpose is to urge the importance of their being interested in the relation of boiler capacity to atmospheric pollution.

J. M. Spitzglass. I would not hesitate to say that the relation between operating efficiency and capacity is *the* most important factor in the boiler room, also in the engine room, and, in fact, in every unit of a plant.

The author had two objects to accomplish in his paper: to demonstrate that the boiler operation should be studied systemati-

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cally in relation to the two fundamental variables, *efficiency* and *capacity*, and to actually study this relation. While he succeeded in accomplishing the first object, he utterly failed in the second.

The author's treatment of the furnace factors is very interesting, indeed. The combination of an air meter and draft gage, assisted by the analysis of flue gases and readings of temperatures, will answer very well if there is always some reliable person whose duty it is to take these various readings.

When it comes to the boiler, however, after demonstrating that the relation between efficiency and capacity is the most important factor in operation, the author does not suggest the direct method of indicating or determining the capacity of the boiler at all times, which is by a steam meter. He merely contents himself with saying that the factors governing furnace operation should also govern boiler operation.

It cannot be denied that some idea of the capacity can be obtained from the conditions of the furnace and measurement of air supply when six extra men, trained for the purpose as was the case in the paper, are present to observe and manipulate the readings of the various devices operated during the test. But how many firemen will be found who are able to observe air velocities, draft-gage readings, gas analyses and flue-gas temperatures; and if they are, how many can interpret them? Many places will be found where most of these instruments are present but are seldom followed by the firemen, but I have yet to see the place where a boiler-steam meter was installed that it was not watched by the firemen the same as the pressure gage or the time clock.

Some may object that the steam-flow meter is not 100 per cent accurate. It is not; neither are any of the attachments to the furnace, as far as we know. The author has demonstrated that under a given set of conditions differential-pressure readings will repeat themselves for the same quantities they represent. It stands to reason that the flow meter, which is merely the index of the differential pressure corresponding to the flow, will repeat itself for the same flow, and by weighing the feedwater for only a short period the absolute calibration may be readily obtained for each boiler or line.

But this calibration, or even the whole accuracy, is not the question of the boiler-steam meter at all. The main object is having something definite and comparatively accurate striking the fireman's eye at all times — something that he can easily understand without any interpretation or calculation.

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The fireman has a problem which we seldom realize. With no steam meter on the line, he does not know what the boiler is actually producing, he merely guesses at it. The demand for steam is out of his control and knowledge. Suppose he learned that by following a certain operation he kept up the pressure at a given time, how is he to know what the actual demand was at that time?

We cannot expect a fireman to operate efficiently from a set of charts drawn up after a boiler test. But when he sees that by performing a certain operation he causes the steam-meter hand to move to the high-capacity side, he visualizes the result and will surely repeat the same operation, knowing it effects better and easier work in general.

R. C. CARPENTER (written). So far as I can now recall, the paper represents the first series of investigations conducted so as to determine the results produced by varying the coal consumption.

It is a matter of regret that in the tests the air supply proved insufficient for complete combustion at the highest limits of coal consumption. Reference to lines 13 and 15 of Table 2 gives information as to the drop in efficiency following the increase in the combustion of coal as indicated on line 3. The determination of the weight of air employed for the combustion of the fuel afforded an opportunity for investigating the effect of the regulation of the air supply, which important item has seldom been given consideration in boiler tests. The particular air meter employed is of interest; so are also the scientific results which are given as deductions from the investigation.

The records of the investigation will be of value in predicting the limit of capacity of steam boilers under similar conditions of operation. An increase of capacity is commercially of importance, for, obviously, as the limit of capacity for a given efficiency is increased, the overhead and operating costs are reduced.

M. ALPERN (written). I take it that the matter of primary interest is a method for securing the highest possible furnace efficiencies, such a method as will be easily followed by a boiler-room operator. Accordingly, I should like to mention some of the things that form a part of the instructions to our own technical operators, and incidentally point out some operating faults which produced such extremely poor results in the tests mentioned by the author.

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Theoretically, the Taylor stoker consists of an inclined retort, throughout which the air pressure is supplied under constant pressure and through constant areas of air discharge; an auxiliary grate surface at the rear of the inclined retort for the purpose of burning out the devolatilized fuel, and a substantially imperforate dump plate on which the residue can remain for a relatively long period, for the purpose of further reducing the carbon in the refuse and discharging the refuse into an ashpit. In operation it is intended that a maximum fuel-burning effect shall take place in the space occupied by the mouth of the retort and that the feed of the fuel in the retort shall be so regulated by the adjustable feeding mechanism that the fuel will rise from the mouth of the retort uniformly throughout. Such of the fuel as remains unburned together with the refuse feeds over the auxiliary grate at the rear, which grate has a hand-regulated air supply. This air supply can be regulated from zero to a maximum opening.

Technical operators are instructed in the operation of the Taylor stoker by observation of the fire only. When properly adjusted and properly operated, the fire will go through a regular cycle. The mixture of fuel and ash will be deposited on the dump plate until the plate is covered to a depth of possibly 12 to 15 in. While the stoker continues to operate, the material is deposited on the dump plate only as the material already there wastes away by the process of combustion and provides room for it. Accordingly, at the end of a period of three or four hours, the material on the dump plate takes on a dead and, to some extent, blackened appearance. This indicates that the time has arrived to dump. At what are normally known as low rates of combustion, that is, rates of combustion below 500 lb. per retort per hour, no air is used on the auxiliary grate; that is, the damper is closed. A small amount of air may escape through leakage. Just prior to the dumping period, for an interval of perhaps 15 min., the damper is open (sometimes wide open, sometimes only part way open). It is only at rates higher than 500 lb. per retort that there is any opening of the damper through the period of operation between dumps. If the stoker does not go through the regular cycle and produce a burned-out ash at the end of a 3- or 4-hr. period, no better indication need be had that one of two things is wrong: either insufficient air is being supplied to the fuel emerging from the retort, or the feed of the lower ram is not adjusted properly. These adjustments are very simple to make. It is apparent in the tests reported by Mr. Phillips

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that the air supplied to the fuel over the retort was insufficient and the damper to the extension grate was wide open all the time, and it would also appear that the fuel bed was not properly adjusted.

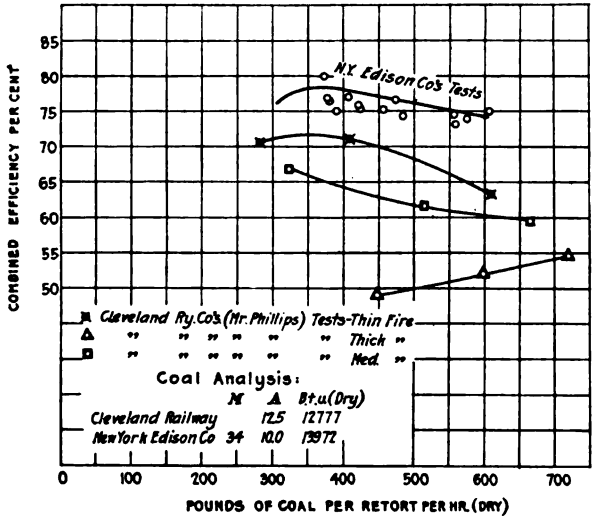

FIG. 10 COMPARISON OF AUTHOR'S AND NEW YORK EDISON COMPANY'S EFFICIENCIES FOR TAYLOR STOKERS

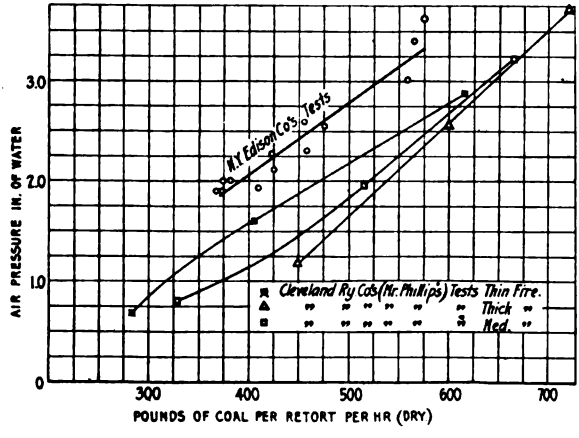

FIG. 11 COMPARISON OF AIR PRESSURES

The accompanying curves will clearly indicate the trouble. In Fig. 10 are plotted first the efficiencies obtained by Mr. Phillips with light, medium and heavy fuel beds. In the same figure are

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shown the efficiencies obtained on the Taylor stoker of exactly similar design with the same ratio of heating surface to grate surface, on tests run at the New York Edison Company's plant. The coal used in the latter tests was somewhat better than the coal used during the Cleveland Railway tests.

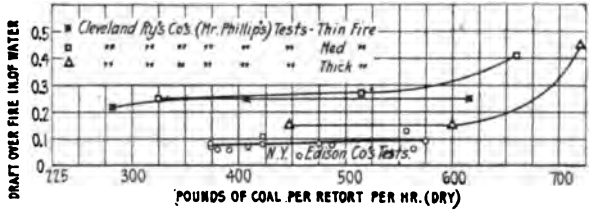

FIG. 12 COMPARISON OF DRAFT OVER FIRE

In Fig. 11 are indicated the air-pressure curves. The air pressures in both the New York Edison tests and the Cleveland Railway tests represent the difference in pressure between the windbox

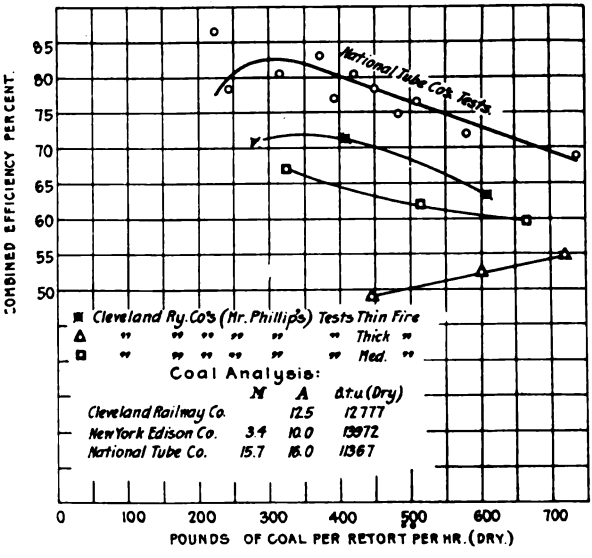

FIG. 13 COMPARISON OF AUTHOR'S AND NATIONAL TUBE COMPANY'S EFFICIENCIES FOR TAYLOR STOKERS

of the stoker and the furnace over the fuel bed. It will be noted that the New York Edison tests show very much higher pressures at corresponding rates of fuel burning.

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Fig. 12 shows the draft over the fire in the case of the New York Edison tests and the Cleveland Railway tests. The draft over the fire in the latter tests was materially higher, as, of course, was the draft throughout the boiler, causing a larger loss from infiltration of air.

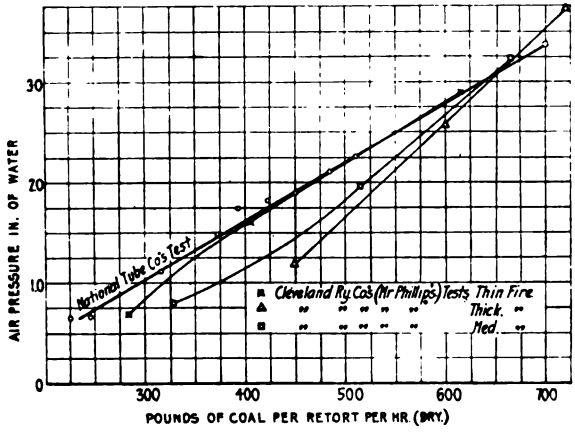

FIG. 14 COMPARISON OF AIR PRESSURES

Fig. 13 illustrates tests run on a Taylor stoker of similar design with a similar ratio of heating surface to grate surface at the National Tube Company's plant, Kewanee, Ill. In this case a much lower grade of fuel was burned than that reported in Mr. Phillips's tests.

Fig. 14 shows the relative air pressures of the National Tube Company tests and the Cleveland Railway tests. In the case of

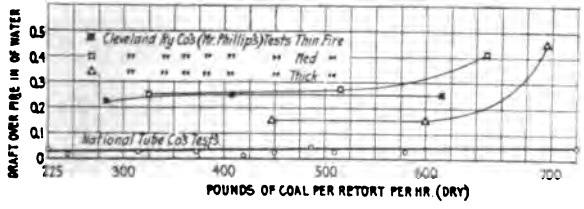

FIG. 15 COMPARISON OF DRAFT OVER FIRE

these tests the air-pressure curves are much closer together, owing to the fact that the actual combustible burned with Illinois coal was much less per pound of dry coal than was true of the coal burned at the Cleveland Railway tests.

Fig. 15 illustrates the draft over the fire.

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Fig. 11 also shows the air pressures used by Mr. Phillips at corresponding rates of combustion per pound of dry coal. It will be noted that with the heaviest fuel bed the lowest air pressures were employed, and with the thinnest fuel bed the highest air pressures were employed, which is just contrary to what is necessary for good operation. The heavy-fuel-bed condition was an unnatural one for the Taylor stoker, and existed only because the fire was starved for lack of air.

GEORGE H. BARRUS (written). The Society is asked in this paper to accept conclusions based on stoker-fired-boiler tests having a duration of only eight hours. This is done in the face of a Code of Rules for Conducting Boiler Tests which the Society has issued, and which makes an 8-hour efficiency test, under the circumstances named, quite unreliable. The paper states that the "fuel bed was kept uniform and constant in thickness by very close and frequent observation on the part of three different men, all experienced firemen." From this it is evident that "the flying start and stop" was the method pursued in beginning and ending the tests. Everyone who has had experience with the operation of Taylor stokers realizes that it is almost impossible for an observer, whether an experienced fireman or even an experienced expert, to judge of the exact condition of the fuel bed in the regular operation of such a stoker. It is therefore well-nigh impossible to make a flying start and stop with a stoker of this kind and be assured that the condition is anywhere near the same at the beginning as at the end of a test. Realizing this, the Power Test Committee of the Society has prescribed certain rules regarding the duration of stoker-fired tests and the method to be employed in starting and stopping them.

In regard to duration, I quote from Par. 45 of the Power Test Report, as follows:

45 In the case of a boiler using a mechanical stoker, the duration, where practicable, should be at least 24 hours. If the stoker is of a type that permits the quantity and condition of the fuel bed at beginning and end of the test to be accurately estimated, the duration may be reduced to 10 hours, or such time as may be required to burn the above noted total of 250 lb. per sq. ft.

In commercial tests where the service requires continuous operation night and day, with frequent shifts of firemen, the duration of the test, whether the boilers are hand-fired or stoker-fired, should be at least 24 hours. Likewise in commercial tests, either of a single boiler or of a plant of

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several boilers, which operate regularly a certain number of hours and during the balance of the day the fires are banked, the duration should not be less than 24 hours.

There is nothing in this paragraph that permits a test of the Taylor type of stoker to be less than 24 hours in duration, in a plant like the one in question operating for 24 hours per day.

I also call attention to Par. 48 of the Power Test Code, which relates to the starting and stopping of a stoker test:

48 To obtain the desired equality of conditions of the fire when a mechanical stoker other than a chain grate is used, the procedure should be modified where practicable, as follows:

Regulate the coal feed so as to burn the fire to the low condition required for cleaning. Shut off the coal-feeding mechanism and fill the hoppers level full. Clean the ash or dump plate, note quickly the depth and condition of the coal on the grate, the water level, the steam pressure, and the time, and record the latter as the starting time. Then start the coal-feeding mechanism, clean the ashpit, and proceed with the regular work of the test.

When the time arrives for the close of the test, shut off the coal-feeding mechanism, fill the hoppers and burn the fire to the same low point as at the beginning. When this condition is reached, note the water level, the steam pressure, and the time, and record the latter as the stopping time. Finally clean the ash plate and haul the ashes.

There is certainly nothing in these requirements that countenances the flying start and stop, which appear to have been employed in the tests reported.

BRYANT BANNISTER[1] (written). The author has invited discussion which should be quite beneficial to boiler-plant designers. It goes without argument that the designer should attempt to provide the maximum of capacity with a given investment, without corresponding contingent losses. With the data available pertaining to heat transmission through setting walls, boiler tubes, etc., we can safely design a boiler plant for what might be termed "intensive steam production."

Since the two greatest sources of heat loss in steam production originate in the boiler furnace and through the boiler proper, we can expect the greatest interference with the design for maximum steam production either in the stoker or the boiler proper. It is possible to meet the first interference by the use of stoker equipment which improves the furnace efficiency as the rate of fuel consumption is increased. One make of stoker has this important characteristic up to a burning rate of about 1000 lb. of coal per retort per hour, and

[1] National Tube Company, Pittsburgh, Pa.

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possibly further. Referring to Fig. 2, it will be noted that a curve connecting the points of maximum furnace efficiency has an upward trend, rising from 68 per cent at a furnace output of 555 boiler hp. to 76 per cent at 1055 boiler hp. output. It then becomes the duty of the boiler unit to absorb the heat evolved without unduly high exit-gas temperatures.

The second interference pertaining to heat transfer into the boiler has been very admirably treated by Messrs. Kreisinger, Ray and Barkley in Bulletin 18 and Technical Paper 114 of the Bureau of Mines. These papers are both splendid arguments for greater capacity from a given boiler heating surface.

Presuming commercially clean tube surfaces, both inside and out, it follows that we must go further than is usually considered good practice toward providing a long gas passage in contact with tube surface, also toward increasing the gas velocity. Just where we should stop with the boiler surface proper and introduce economizer surface must, of course, be governed by local conditions, costs, etc., but the writer believes that such economizer surface can be provided adjacent to the boiler, preferably above, with tubes of suitable size and so arranged that high gas velocity is obtained, in many cases with a single pass for gas flow.

Because large boiler units lend themselves so well to the above scheme, they should be given consideration as an essential feature in the design.

If the principle of "intensive steam production" is adhered to in both design and operation, the result will be minimum investment per unit of steam produced, while the cost of operation, including fuel, labor and material for repairs and maintenance, etc., will not be increased much over similar costs for normal steam production.

The tendency toward the proposed design is apparent in central-station construction, and the writer hopes that it will be appreciated and followed for the average industrial boiler plant of the future.

N. G. Reinicker (written). The author is correct in his statements of the importance of efficiency and capacity, but any conclusions regarding these items, based upon the tests reported, will be entirely out of accord with results which can be and are being obtained with similar equipment and coal throughout the country.

The fact that the runs were of only eight hours' duration leaves room for wide variation in results. In furnaces having a large amount

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of fuel on the grate, as is the case with the underfeed stoker, it is possible in an 8-hr. test to get any efficiency desired. Twenty-four hours is the minimum time in which such runs should be made.

In every test reported there was a large deficiency of air. The furnace was apparently used as a gas producer, with secondary combustion in some of the passes, as shown by the exit-gas temperatures and CO loss, and undoubtedly considerable smoke came from the stack.

The drafts for all runs show no consistency, especially furnace draft, which is much higher than necessary. The air pressure under the tuyeres should have been from $\frac{1}{4}$ in. to 1 in. higher to supply the required air to burn the coal.

Assuming the tests were greater in number, more carefully run, and representative of the equipment and coal used, the conclusions reached from an analysis of the Combined Boiler-Unit Operation Chart would be of no value to an operating man. The experience of trying to pick from a chart the air pressure required for any rate of burning coal is like the experience gained by a number of engineers who bought tachometers for their stokers and had a second scale added showing the air pressure the fireman should carry for that stoker speed. They found the second scale of no value.

The author fails to mention the most important item controlling capacity and efficiency in an underfeed-stoker furnace, and that is the temperature at which the ash fuses. With a coal causing considerable clinker, air quantity will not affect capacity unless the air can be made to distribute through the fuel bed, and not through holes in the fire. Clinker will cause holes and will limit capacity and reduce efficiency.

Less attention should be paid to convection and radiation, the losses from these items being such a small part of the total losses in a boiler-and-furnace heat balance, and much more attention paid to losses from combustible in the ash and from CO, which losses together, using the equipment and coal of these tests, should not be more than 10 per cent of the total heat supplied.

C. F. Hirshfeld (written). There are three distinct subjects treated in the paper and they should be recognized as such and separately considered. These subjects are:

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1 A discussion of the combustion of solid fuel on chain grates and on underfeed stokers, with a suggestion as to the essential variables and means for their indication and control
2 A discussion of the factors influencing the efficiency of the boiling vessel
3 A demonstration of the fact that the efficiency of the furnace as a heat liberator and the efficiency of the boiling vessel as a heat absorber are interrelated, and that there is one set of furnace conditions at each load which gives the best efficiency for the combination.

With reference to the discussion of combustion and its control, there has been a very general recognition recently of the fact that the burning of coal under steam boilers can be reduced to a fairly exact procedure if the proper indicating instruments are supplied. It has also been recognized that if the best results are to be obtained it is not sufficient to supply only instruments by means of which the operator may measure the degree of success achieved. It is also necessary to furnish instruments which will measure for the operator the values of the various variables which combine to give the indicated result, in order that he may be able to change the values of these variables wisely and methodically for the purpose of obtaining the highest possible effect.

The author proposes thickness of fuel bed and pressure drop through the fuel bed as the important controlling variables. He further proposes an inferential method of determining fuel-bed thickness: namely, the measurement of the quantity of air passing through the fuel bed in a given time and the pressure drop required to force this quantity of air through the bed.

If the operation is to be conducted by men of such mental caliber that they cannot be educated beyond the point required to enable them to keep the indications of two instruments at prescribed points, it is admitted that the author's suggested method of furnace control will probably give as satisfactory average results as can be obtained under those conditions. However, it may be pointed out that it represents little if any advance over the automatic interlock between fan speed and stoker speed, originally a characteristic part of a Taylor-stoker installation.

If the operation is to be conducted by men of such mental caliber that they can be educated to a true appreciation of the meaning of all or most of the variables which interact to give a certain

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result in the furnace, then the proposed method will be decidedly inadequate and imperfect, particularly as applied to underfeed stokers. In this case the pressure drop through the bed, taken in conjunction with the quantity of air passing, would be a true indication of the average thickness of the fuel bed if that bed were always formed of coal of the same kind and size, if the damper settings on extension grates and other controllable points were always the same, and if the character of the fire as influenced by its past history were always the same. Unfortunately, all of these variables have marked effects.

To take extreme illustrations, assume, for one case, that an operator has managed to pile up a thick fire at the top of the stoker and has burned it very thin toward the toe; and for another case, that he has forwarded the fuel more rapidly than he should have, so that he has a thin fuel bed near the top of the stoker and a thick fuel bed near the toe. In each case he would obtain and observe some definite pressure drop which would correspond to perfect fires of certain definite thicknesses, and yet his fire would be far from perfect. Or again, assume the character of the coal and its method of combustion to be such that there is serious clinkering in spots, with burning through in others. Such a condition would give a pressure drop corresponding to some definite thickness of perfect fuel bed, and yet the actual conditions would be far different.

After all is said and done, optical inspection of the fire and a good knowledge of its past history are required if the best results are to be obtained. The combination of such inspection and such knowledge with the readings of properly chosen instruments, by an operator educated to the point where he can appreciate the true significance of all facts and indications, is the most promising method of obtaining high efficiencies.

The firing methods in use in the boiler rooms of The Detroit Edison Company practically include the features which the author proposes, but others have been added and it is recognized that more must be added before the best control now in sight can be attained. At the plants of this company it is customary to maintain a certain definite draft at a chosen point above the fire and to vary the underfire pressure to suit conditions. This arrangement gives the fireman a measure of the pressure drop through the fire. The quantity of air used is not measured in conventional units but in terms of blower speed and resistance through the bed, which is just as good a combination measurement so far as the operation is concerned.

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No attempt to reduce coördinated readings to chart form has been made, because the constant effort of the engineers has been devoted to the education of the men to such a point that they could reason from the known condition of their fire and the readings of their instruments, instead of going it blind on the basis of charts which at best can represent only average conditions.

In these plants it has been found advisable to supply instruments for indicating stoker speed, carbon-dioxide content of flue gases, temperature of flue gases and boiler output, as well as the values mentioned above, and it has also been found advisable to supply numerous dampers for controlling the distribution of air to the various parts of the fire. With all of these tools in the hands of thinking operators, remarkably good results are obtained and maintained.

The author has performed a real service in emphasizing, in what have been previously referred to as the second and third parts of his paper, the known fact that the best overall efficiency of the unit is really the product of the efficiencies of its two component parts and that the best combined efficiency might not correspond to the highest efficiency of furnace or of boiler. There are astoundingly few figures available by means of which one may even approximately determine values of this sort, and it would be of great value to the industry if typical units could be tested over wide ranges with respect to all essential variables in about the same way as was the unit tested by the author of the paper.

Unfortunately for the type of control advocated and for the worth of the data submitted, the tests recorded in the paper do not seem to represent good furnace practice. The so-called overall efficiencies are low, even for modern operating conditions under variable loads, and are correspondingly lower in comparison with what would be expected under test conditions.

Moreover, when these efficiencies are considered in conjunction with the stated thickness of fire and the under-fire pressure, one is driven to the conclusion that what the author calls a thin fire must really be thick and what he calls a medium fire must be very thick, or else that some other variable of great importance must have been neglected. The flue-gas temperatures and carbon in refuse also appear to be abnormally high for the various loads and conditions to which they correspond.

THE AUTHOR. In their discussions both Mr. Barrus and Mr. Reinicker are unwilling to attach any accuracy to tests of eight

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hours' duration. The author understands fully the validity of objections to eight-hour tests, and the tests in question were conducted with these objections in mind. They could not have been conducted otherwise. As regards the degree of accuracy of the efficiencies obtained, it may be said that the closely accurate determination of efficiency was throughout of secondary importance. None of the data sought or conclusions reached is impaired by an inaccuracy of, say, 3 per cent in the overall efficiency. The overall efficiency is the only quantity that the employment of the short test can bring into question. It will be noted that differences in efficiency by virtue of differences in fuel-bed thickness are far in excess of any possible inaccuracy in the values of efficiency. Furthermore, all other observations and the conclusions drawn therefrom are in no way subject to the criticism of the short duration. It is quite conceivable that the curvature or slope of some of the lines on the furnace and boiler-unit operation charts may be appreciably in error. These charts were presented, however, to illustrate certain general principles, and are believed to be of sufficient accuracy to serve this purpose. The entire part of the paper relating to the boiler as a heat absorber is, of course, not subject to the above criticisms.

The reason for the short tests was the impossibility of operating for a longer period at the heavy overloads. It will be noted that the coal used was very high in sulphur. The resultant difficulties with clinker building out from the bridge wall prevented continuing these tests over eight hours. The eight-hour test was adopted for this investigation only after considerable experimentation. It was found that very small changes in the fuel supply could be readily observed in their effect upon the fuel-bed thickness. In considering the accuracy of the tests it must be remembered that firing conditions were kept very constant. Every effort was made to this end. Under such conditions, objections to the eight-hour test are minimized. In view of the observed fact that cutting off the fuel supply for five minutes produced an easily observed change in the fuel bed, the author feels justified in claiming an accuracy in efficiency figures within a 3 per cent limit of variation.

Mr. Spitzglass speaks of the author's failure to study the relation between efficiency and capacity. The author would say here that, assuming the possession of complete data on the operating characteristics of a steam boiler, the study of the above relation must necessarily be a prolonged affair. It involves the loading

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conditions of the plant, prices of coal and labor, cost of equipment and of land and other conditions affecting power costs. Manifestly it could not be so much as touched upon in the present paper. All that the author hoped to do was to establish the importance of the relation of efficiency to capacity in the boiler as the prime basis of the investigation which has been presented.

Mr. Spitzglass also questions the ability of the fireman "to observe air velocities, draft-gage readings, gas analysis and the flue temperatures," or to interpret such readings. As regards flue-gas analyses, the author fully agrees with Mr. Spitzglass and takes great pains in the paper to point out how the conditions of combustion may otherwise be easily and simply indicated. As regards the observing of air velocities, the author believes that the air meter, an illustration of which is shown in the paper, may be read as easily as any other form of meter. Concerning the use of instruments in general, the practice of the best plants throughout the country is a sufficient answer. The author heartily subscribes to the value of the steam-flow meter as mentioned by Mr. Spitzglass.

The author wishes to correct the impression that may have been gained that he ever had in mind the use by the fireman of charts such as have been presented in this paper. He would, however, propose the use of scales on the various instruments, having the numbers so arranged as to correspond when operating conditions are proper; e.g., all numbers indicating *5* when No. 5 load is to be carried. Such a system would be readily intelligible to the fireman. Necessarily, the fireman could never be guided by it exclusively, but it would constitute an average basis for the comparison and better understanding of firing conditions, and a guide at all times.

Messrs. Alpern and Reinicker both call into question the matter of air-pressure drops through the tuyeres and fuel bed (i.e., sum of pressure in air boxes of stoker and draft in combustion chamber). Clearly this drop is a function of the amount of air forced through the fuel bed, the areas of air openings in the grates, and the thickness and resistance of the fuel bed. The criticisms seem to assume ability on the part of the operator to regulate this pressure drop independently of load. Such cannot be the case, since any increase in air pressure with a given condition of fuel bed will simply result in a greater combustion rate and will not change proportionately to any extent the ratio of air to coal burned. This ratio may be regulated only by regulation of the fuel-bed resistance.

Mr. Alpern speaks of "some operating faults of the tests." The

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author has nowhere indicated that the air supply to the extension grates was kept continuously at the maximum, nor does Mr. Alpern's discussion indicate to him any faults in operation. The point is that at heavy overloads it is obviously necessary to increase the combustion rates on all parts of the grate surface. This necessity applies to the extension grates as well. The author does not believe that the maximum supply of air to these grates is sufficient for prolonged overloads in the stoker under discussion. Mr. Alpern's statement regarding the relation of air pressures to the different fuel-bed thicknesses is not in accord with the data given in the paper. The author certainly agrees with Mr. Alpern that "the heavy-fuel-bed condition was an unnatural one."

In answer to Mr. Reinicker's statement that the furnace drafts were too high, the author would say that in the particular setting tested, lesser drafts could not be used without driving some gas out of the setting near the top of the first pass and without endangering dump-grate bars. The author fully agrees with Mr. Reinicker as regards the limitations placed upon both capacity and efficiency by high furnace temperatures. Difficulties from clinker and destruction of the refractory lining are perhaps the greatest single barriers operating against heavy overloading. Mr. Reinicker's statement regarding the unimportance of radiation and convection as *losses* and his criticism based thereon have no bearing on the paper under discussion. The author treated radiation and convection as the modes of heat transmission from the furnace to the boiler and at no point considered their bearing upon the incidental losses from the setting.

The author considers Mr. Hirshfeld's discussion especially interesting and pertinent. His observations as to optical inspection of the fire are unquestionably correct. Optical observation, as Mr. Hirshfeld indicates, supplements the use of indicating instruments but does not displace them. As regards the peculiar fire-bed conditions described in this discussion, the author does not believe that such conditions would even be approached in the course of properly uniform operation of the stoker. The question of holes and lack of uniformity due to clinker has been taken up in the paper itself, where it is shown that the proposed instruments are of value in this connection. The author is glad to have Mr. Hirshfeld reiterate the divisions into which the subject-matter of the paper properly falls.

In several of the discussions presented the overall efficiencies have been criticised as being low. The author would like to state by

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way of explanation that the analyses of the coal do not fully indicate its character, and that the coal used was not only high in sulphur and productive of great difficulty with clinker, but was slack of the poorest grade as regards structure, with a large proportion of dust.

In the first paragraph of his discussion, William Kent has put in a few words the idea that has been in the mind of the author for some years, and which led to the preparation of this paper.

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No. 1586

RADIATION ERROR IN MEASURING TEMPERATURE OF GASES

By Henry Kreisinger, Pittsburgh, Pa.
Member of the Society
AND
J. F. Barkley,[1] Pittsburgh, Pa.
Non-Member

In measuring the temperature of a stream of hot gases surrounded by colder or hotter surfaces, heat radiates to or from the measuring instrument, making it read high or low, and the difference between the true temperature of the gases and that indicated by the instrument is called the radiation error.

The paper enumerates the factors with which this error varies, and to show the magnitude of the effects of some of them, gives results of a series of measurements made with thermocouples placed at different points along the paths of gases flowing through water-tube boilers, citing one instance where the error under certain conditions can be as much as 320 deg. cent.

WHILE investigating the temperatures of gases in boiler settings the Bureau of Mines found it necessary to study the errors of the current temperature-measuring methods. Of the errors entering into the determination of the average temperature of a stream of hot gases surrounded by colder or hotter surfaces, the radiation error is the most serious one and the most difficult to correct. Ordinary temperature measurements made with commercial devices under such conditions are from 5 to 25 per cent in error. If the surrounding surfaces are cooler than the gases, the temperatures indicated by the measuring instrument will be too low; or if the surrounding surfaces are hotter, as is the case in regenerating furnaces, the temperatures indicated will be too high.

2 The object of this paper is to show primarily how large the radiation error may become under certain conditions of temperature measurements, and that judgment must be used in interpreting the accuracy and the value of temperature readings.

[1] Junior Electrical Engineer, U.S. Bureau of Mines.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of The American Society of Mechanical Engineers. By permission of the Director of the Bureau of Mines.

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NATURE OF RADIATION ERROR

3 The radiation error is due to the fact that, to a large extent, gases are permeable to radiation. When a temperature-measuring instrument is immersed in a stream of hot gases surrounded by cooler surfaces, it absorbs heat from the gases by convection and its temperature rises. As soon as its temperature exceeds that of the surrounding surfaces, heat passes by radiation from the instrument to these surfaces through the intervening gases. Thus the in-instrument receives heat from the hot gases by convection, and gives off heat by radiation to the surrounding colder surfaces. The temperature of the instrument continues to rise with a decreasing rate, until the quantity of heat it gives off is equal to the quantity of heat it receives; the temperature then remains constant. Under these equilibrium conditions the temperature of the instrument is between that of the stream of gases and that of the surrounding surfaces; in other words, it is lower than the temperature of the gases which it is intended to measure.

4 When the instrument is inserted in a stream of gases surrounded by surfaces hotter than the gases, it receives heat by radiation from the hot surfaces and at first also by convection from the stream of gases, and its temperature rises. When the temperature of the instrument has risen above the temperature of the gases, the flow of heat from the gases to the instrument reverses, the instrument begins to give off heat by convection to the hot gases, and receives heat only by radiation from the surrounding surfaces. The rise of temperature of the instrument continues at a rapidly decreasing rate until the quantity of heat received by the instrument by radiation from the hot surfaces is equal to the quantity given off to the stream of gas; the temperature of the instrument then remains constant. With these equilibrium conditions the temperature of the instrument is somewhere between that of the surrounding surfaces and that of the stream of gases; in other words, it is higher than the temperature of the gases which the instrument is supposed to measure. The difference between the temperature of the gases and that indicated by the instrument is the radiation error.

5 The magnitude of the error depends mainly on (1) the size of the part of the instrument exposed to the gases and the radiation, and (2) the difference between the temperature of the gases and the temperature of the surrounding surfaces. The smaller the exposed part of the measuring instrument, the smaller the radiation

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error; also, the smaller the difference between the temperature of gases and the temperature of the surrounding surfaces the smaller the radiation error. In the measurement of the temperature of gases only the first-named factor can be controlled. The second factor is fixed by the kind of the apparatus and its operation.

6 Of the instruments used in the measurement of temperature of gases, the thermocouple lends itself the best to the reduction of its size. It can be made so small that the radiation error is negligible

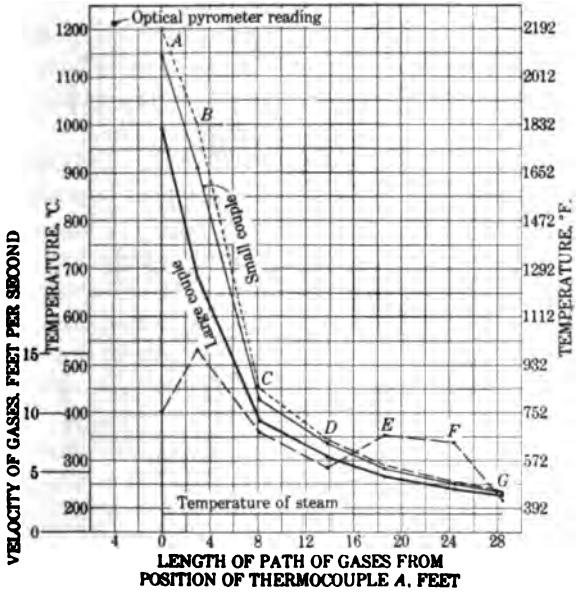

FIG. 1 TEMPERATURE OF GASES AS THEY PASS THROUGH A BABCOCK AND WILCOX BOILER

The heavy curve connects readings obtained with a couple 0.5 in. in diameter and the light curve readings obtained with a couple 0.008 in. in diameter. Dotted curve is estimated true temperature of gases. Curve drawn in dashes shows approximate velocity of gases.

for practical purposes. The correct temperature would be indicated only by a thermocouple having an exposed hot junction made of wires of zero diameter, which, of course, is a physical impossibility.

TEMPERATURE MEASUREMENTS IN A BABCOCK AND WILCOX BOILER TO DETERMINE EFFECT OF SIZE OF THERMOCOUPLES

7 The effect of the size of thermocouples is shown in Fig. 1, which gives two sets of temperature measurements of the gases

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passing through a Babcock and Wilcox boiler[1] fired with natural gas. One of these sets of measurements was taken with thermocouples having the hot junction made of wires 0.008 in. in diameter and the other set with couples having the hot junction parts made of tubes about 0.500 in. in diameter. This large couple is about the size of commercial instruments used for such purposes. Several thermocouples of each size were made and clamped together in pairs, each pair containing a large couple and a small couple, with their

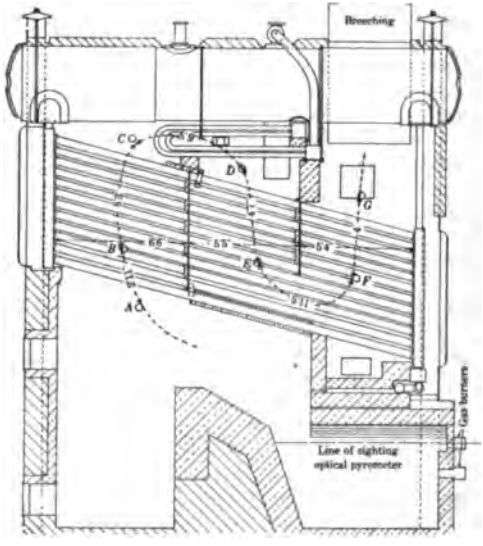

FIG. 2 SETTING OF GAS-FIRED BABCOCK AND WILCOX BOILER IN WHICH THE MEASUREMENTS WERE MADE. TOTAL HEATING SURFACE, 3400 SQ. FT.; STEAM PRESSURE, 165 LB. BY GAGE

hot junctions about 1½ in. apart. These pairs were placed at different points along the path of gases, indicated by the small circles and designated by the letters *A*, *B*, *C*, *D*, *E*, and *F* in Fig. 2. All the couples were connected to a central switch and read in rapid succession with a portable potentiometer. While the readings were taken the furnace conditions were kept uniform, which was a comparatively easy task with the gas firing.

8 In Fig. 1 the abscissæ are the approximate lengths of the paths of gases, measured from the position of the first pair of couples

[1] One of several boilers in the power plant of the Carnegie Technical Schools, Pittsburgh, Pa., which were placed at the disposal of the authors for their investigations, through the courtesy of Prof. W. Trinks, Mem.Am.Soc.M.E.

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A. The full heavy curve connects the readings obtained with the large couples, and the full light curve the readings obtained with the small couple. The dotted curve above the full curves gives the probable true temperature of the gases which was obtained by extrapolation from the readings of the two couples of different sizes by means of curves similar to those shown in Fig. 6. The curve near the bottom of the figure (drawn with dashes) gives the approximate velocity of the gases computed from the volume of gas burned, the chemical analysis of the products of combustion and the true temperature of the gases. The small black circle at the upper left-hand corner gives the furnace temperature as measured with the Wanner optical pyrometer sighted through one of the gas burners, as shown in Fig. 2.

9 The two full curves of Fig. 1 indicate that the small couples consistently showed temperatures considerably higher than the large couples, although the small couples themselves read somewhat too low. The difference between the readings of the two couples is nearly proportional to the difference between the true temperature of the gases and the temperature of the surrounding boiler surfaces which was about 50 deg. higher than the temperature of steam in the boiler. The large couple at *B* shows a radiation error of about 575 deg. fahr., whereas the small couple at the same place indicates an error of only 150 deg. fahr. In position *F* where the temperature of the gases is much lower, the large couple reads only about 25 deg. fahr. too low, and the small couple shows an error of only 5 deg. fahr.

DESCRIPTION OF THERMOCOUPLES

10 Two kinds of couples were used in these temperature measurements: copper and constantan for temperatures up to 900 deg. fahr. and platinum and platinum-rhodium for all higher temperatures.

11 The details of both kinds of couples are indicated in Fig. 3, the upper half of the figure showing the copper-constantan couples and the lower half the platinum couples. A feature of interest in connection with the subject of this paper is that the hot junctions on all of the small couples were made of short pieces of wire 0.008 in. in diameter, welded to larger wires in order to obtain mechanical strength and to avoid sagging of the projecting parts. In each couple the two dissimilar small wires forming the hot junction at the bend are kept uniform in diameter without the formation of the usual bead.

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12 The large copper-constantan couples were made of thin-walled copper tubes, 0.550 in. in outside diameter, having a cup-shaped copper plug rolled into one end. The hot junctions were made by peening into these plugs constantan wires 0.025 in. in diameter. The constantan wires were placed into the copper tubes, from which they were insulated with glass tubing.

13 The large platinum couples were made of wires 0.025 in. in diameter. The hot-junction end of the couples was placed in a closed-end silica tube, about 11 in. long and fitted into a water-cooled metal holder. The closed-end silica tubes were 0.450 in.

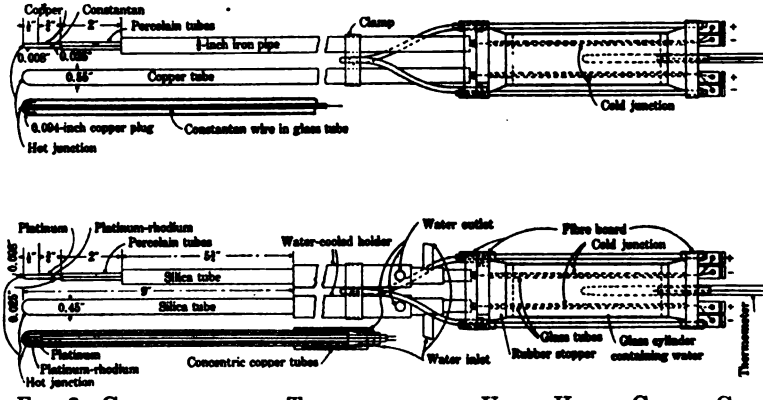

FIG. 3 CONSTRUCTION OF THERMOCOUPLES. UPPER HALF, COPPER-CONSTANTAN COUPLES; LOWER HALF, PLATINUM AND PLATINUM-RHODIUM COUPLES

outside diameter, and inasmuch as it was the outside surface of these tubes which received and gave off heat, this construction gave the same readings as would have been obtained with couples made of a large platinum tube in a similar way as the large copper couples. The length of the silica tubes was sufficient to make negligible any lowering of temperature of the closed end due to conduction of heat to the water-cooled holder. (The Bureau of Standards, when calibrating thermocouples at high temperatures, uses an immersion of 25 cm. or about 9¾ in.)

14 The water-cooled holder of the platinum couples was made of three concentric copper tubes arranged in such a way that the cooling water flowed twice the full length of the holder. The outside tube was ¾ in. in outside diameter, making the holder of convenient size for manipulation. The cold junctions of the couples were placed in a water bath attached to the cold end of the couples as shown in Fig. 3.

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THE EFFECT OF TEMPERATURE AND THE NATURE OF EXPOSURE OF COUPLES ON RADIATION ERROR

15 Fig. 4 shows how much lower the large couples read than the small ones when the couples were placed in the boiler settings

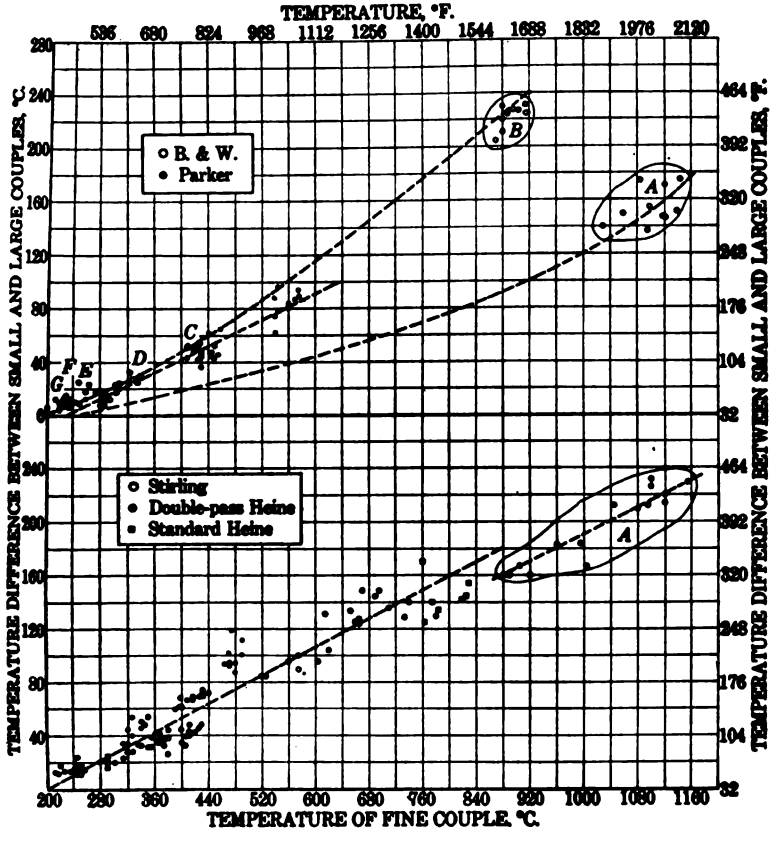

FIG. 4 EFFECT OF TEMPERATURE OF GASES ON RADIATION ERROR IN VARIOUS TYPES OF BOILERS

of five of the common types of water-tube boilers. The readings were plotted on two charts to avoid crowding the points. With the exception of the groups marked *A*, all the readings were obtained with the thermocouples placed among the tubes, or in other places where they were almost totally exposed to the heating surfaces of the boilers.

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16 The group *A* of the Babcock and Wilcox boiler was obtained with the thermocouple placed in position *A*, Fig. 2. In this position the thermocouples were exposed partly to the boiler tubes and partly to the brick walls and the clay-tile furnace roof, which latter surfaces were much hotter than the boiler tubes. Therefore the thermocouples did not lose as much heat by radiation as those couples which were completely surrounded by the boiler tubes, and their radiation error was smaller.

17 Group *A* of the lower half of Fig. 4 was obtained with the couples placed about 1 ft. above the arch and 1 ft. from the front

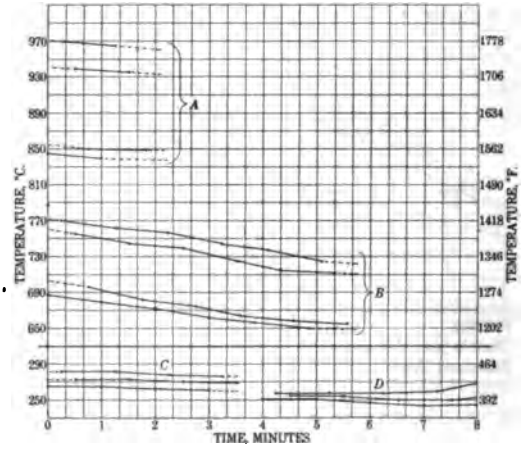

FIG. 5 EFFECT OF SIZE OF COUPLE ON TEMPERATURE IT INDICATES

nest of tubes in a setting of a standard Stirling boiler. They were therefore exposed partly to the boiler tubes and to some extent also to the hot brickwork of the furnace. Therefore the radiation error of these couples was somewhat smaller than the radiation error of the other couples completely surrounded by the boiler tubes.

18 Dotted curves were drawn through the groups of points representing readings of couples having nearly the same exposure to indicate that the radiation error is roughly proportional to the temperature of the gases.

RELATION BETWEEN RADIATION ERROR AND SIZE OF INSTRUMENT

19 To determine the nature of the relation between the radiation error and the size of the hot junction of a thermocouple, four thermocouples of different sizes were clamped together and placed in the

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setting of a Heine boiler in a position similar to *A*, Fig. 2. The diameters of the hot junctions of these couples were 0.008, 0.025, 0.31 and 0.45 in. These couples were clamped together in such a way that the two small couples were between the large ones, the distance between the hot junctions of the two end couples being 4 in. The couples were read in rapid succession by means of a multiple switch and a potentiometer. In Fig. 5, *A* and *B* give two series of such readings, falling in the order of the size of the couples, the smallest couple reading the highest. Individual readings are represented by the dots, and the readings of each couple are connected by a broken line.

20 A similar set of three couples was placed in the uptake of the same Heine boiler. The diameter of the hot junctions of these couples were 0.008, 0.25 and 0.55 in. Two series of readings taken with these couples are given in *C* and *D*, Fig. 5, the readings falling in the order of the size of the couple, the smallest reading the highest. That is, in all cases the smallest couple has the smallest radiation error and therefore reads the nearest to the true temperature of gases.

21 It is apparent that the radiation error has a definite relation to the size of the part of the couple containing the hot junction. Very likely it is the extent of the surface of the hot junction which determines the magnitude of the radiation error. Inasmuch as the surface is proportional to the diameter, the radiation error should have a rather definite relation to the diameter of the hot-junction part of the couple. To test this relation the averages of the two series of readings, *A* and *B* of Fig. 5, were plotted on the diameters of the couples as abscissæ, and are given as curves *A* and *B* in Fig. 6. The points of curve *M* at the bottom of the figure are the averages of several series of readings obtained with the three couples placed in the uptake of the Heine boiler. The approximate average temperature of the surrounding surfaces for each set of points is shown by the dotted lines. All three curves have been extended to a point of zero diameter, giving approximately the true temperature of the gases.

22 The shape of the curve is shown the best by curves *A* and *B*, having four points each. As the diameter of the hot junction of the couple decreases, the temperature indicated by the couple rises, at first very slowly, but after the diameter of about 0.100 in. is passed this rise in temperature becomes very rapid; and also, the greater the difference between the temperature of gases and that of the surrounding surfaces, the steeper this rise. In all these three curves

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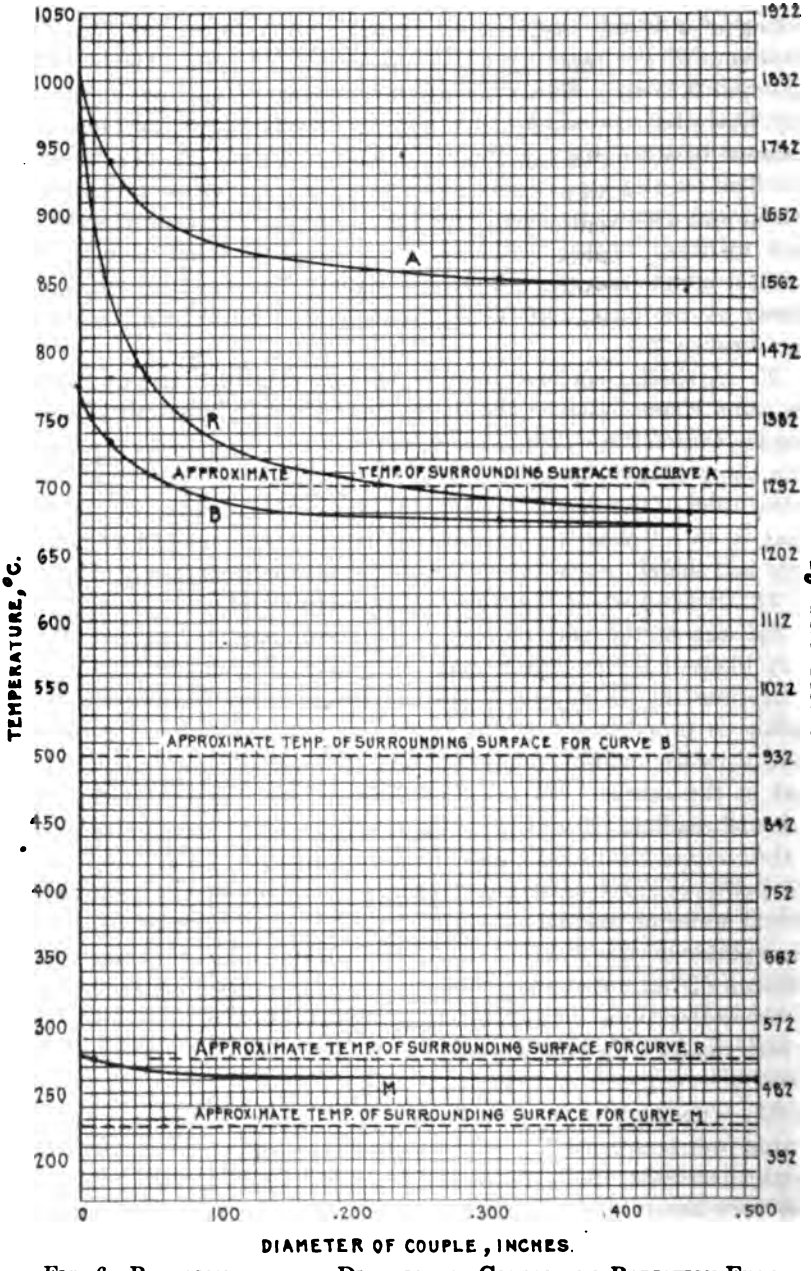

FIG. 6 RELATION BETWEEN DIAMETER OF COUPLE AND RADIATION ERROR WHEN THE GASES ARE SURROUNDED BY SURFACES AT DIFFERENT TEMPERATURES

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the temperature difference between the gases and surrounding surfaces is comparatively small. Among the boiler tubes near the entrance of furnace gases this temperature difference is very large, and therefore for that position the part of the curve below the diameter of the hot junction of 0.1 in. is very steep. Curve *R* represents such conditions; the two points of the curve are the readings obtained with the two couples placed at *B* in the Babcock and Wilcox boiler, and plotted in Fig. 1. The shape of the curve *R* has been determined by studying the curves *A* and *B*. The shape of the curves may also be derived mathematically. Curves similar to *R* were prepared for the readings of the couples in other positions, and the points where these curves met the zero diameter line have been used in plotting the dotted curve in Fig. 1, giving the approximate true temperature of the gases.

DISCUSSION

E. A. Fessenden and R. B. Fehr (written). The paper is of decided value in calling attention to a source of error that has heretofore been almost universally neglected. It is, of course, obvious that there is no radiation error where the temperature-measuring device is completely surrounded by surfaces at the same temperature as the medium whose temperature is being measured. Many experiments concerning gas temperatures in steam boilers, however, have failed to be of material value because the conclusions have been based upon direct temperature measurements of gases surrounded by comparatively cool surfaces.

In Par. 21 it is stated that "very likely it is the extent of the surface of the hot junction which determines the magnitude of the radiation error." It is not clear, however, just what is meant by "the surface of the hot junction." Apparently the authors have taken this to mean the surface of a cylinder whose diameter is that of the junction, which in their case was made the same as the diameter of the elements. No mention is made, however, of the length of this cylinder, and the surfaces have been assumed to be proportional to the diameters. The effects of conduction along the elements from the couple ought to be discussed in connection with these radiation effects. It would seem, therefore, that the length of the cylindrical surface as well as the diameter should be considered on account of the effect of the conduction of heat to or from the hot junction. Three cases may be noted:

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1 Where the couple leads are surrounded by material of the same temperature as the junction (as, for example, in the authors' experiments in which the couple leads are perpendicular to the direction of flow of a large volume of gases), the temperature of the leads is the same as that of the junction and no conduction effects are produced.

2 Where the couple leads are surrounded by material cooler than at the junction, the temperature of the leads will be lower than that of the junction so that heat will be conducted away from the junction by the leads. The amount of heat carried away from the junction in this manner, and consequently the lowering of the junction temperature, will depend upon the material of the leads, their cross-section, and the temperature gradient. An example of this condition is the case where the couple is inserted in a boiler tube in which the gases are flowing parallel to the couple leads and with the hot junction pointing upstream.

3 This case is similar to the second one except that the material surrounding the leads is hotter than at the junction, as when a thermocouple in a boiler tube points downstream. Here heat will flow toward the junction and tend to raise its temperature.

In the second case radiation to cooler surrounding surfaces and conduction along the elements both tend to make the reading lower than the actual temperature of the substance, while in the third case conduction tends to raise the reading and radiation to lower it.

It is to be hoped that this paper may be considered as preliminary, and that the authors will continue these investigations and at a later date give definite and quantitative information as to the effects of radiation and conduction upon thermocouples, taking into account:

a Size and material of couple elements
b Size of bead at hot junction
c Length of exposed elements
d Size and kind of protecting tubes
e Application of Stefan-Boltzmann law
f Temperature gradient in the substance surrounding the leads.

HENRY KREISINGER. Replying to the suggestion of Messrs. Fessenden and Fehr that the effects of conduction along the elements

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of the couples should have been discussed along with radiation effects, I would say that this point is simply a question of how complete a treatise on the errors in measuring the temperature of gases one wishes to write. The authors decided to treat the radiation error, and limit themselves in the present paper to this error as far as practicable. The thermocouples they used in their experimental work were so constructed and the experiments so planned that the conduction effect was eliminated.

In all cases the leads from the hot junction are sufficiently long as compared to their cross-section that any lowering of the temperature of the hot junctions by heat conduction along these leads is prevented. With the smallest couples the leads are 0.008 in. in diameter for a length of ½ in., and then 0.025 in. in diameter for a length of ¾ in. The cross-sections of these leads are too small for heat to be conducted along their lengths. Within the lengths of these leads the temperature gradient of the gases can be but very small. This construction of the couples is very well adapted to the measuring of temperature of gases within a boiler tube, as cited in the second case noted by Messrs. Fessenden and Fehr.

The large copper-constantan couples are made of copper tubing ½ in. in diameter, having a wall 0.052 in. thick. This tube which forms the leads was immersed in the gases for a length of about four feet. The temperature gradient for a large part of this length is very small, so that it is not necessary to consider the conduction of heat from the hot junction along the leads. The same can be said as to conduction of heat along the protecting silica tube of the large platinum thermocouples.

The surface of the hot junction of the small couples may be considered as a cylinder, but in the large couple this surface is partly a sphere and partly a cylinder. Just how much of each should be considered is difficult to determine. The particular construction of the large couple was adopted because it is simple and inexpensive, and mainly because commercial thermocouples are of a similar design.

It should be added that the hot junctions of all the couples were placed in the center of the stream of gases and pulled out by steps, temperature readings being taken every two inches to determine temperature gradient of gases. The results of this part of the experiments are given in detail in the Bureau of Mines' publication on Measuring the Temperature of Gases Inside Boiler Settings.

The fact that the radiation error becomes smaller as the diameter

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of the couple decreases may be explained without going into too detailed refinements in the following manner: The couple receives heat from the gases by convection and gives it off by radiation. When the temperature of the couple is constant the quantity of heat received by the couple is equal to the quantity given off by radiation. The convection does not impart the heat directly to the metal of the couple but to the outside surface of a gas film adhering to the solid. Through this gas film the heat passes by conduction. On the other hand, the heat is radiated directly from the surface of the metal through the layer of gas.

The quantity of heat that is received or given off by the couple depends on temperature difference and the extent of the surface receiving or giving off the heat. Since the thickness δ of the gas film remains practically constant no matter what the diameter of the couple is, it is apparent that as the diameter of the couple decreases the heat-radiating surface decreases faster than the heat-receiving surface of the gas film. The effect of the unequal decrease of the two surfaces is especially marked when the diameter of the couple becomes less than the thickness of the gas film. As the zero diameter of the couple is approached the ratio of the heat-receiving surface to the radiating surface becomes infinitely large, the radiation ceases, and the temperature of the couple becomes the same as the temperature of the gases.

Following this course of reasoning, it is possible to apply the Stefan-Boltzmann radiation law and the law governing the heat transmission by convection and derive an equation expressing the relation between the diameter of a couple and the true temperature of the gases when the temperature of the surrounding surfaces and the temperature of the couple are given. The temperature of the couple is read when the quantity of heat received by convection is equal to the quantity given off by radiation; or if H_c designates the heat received and H_r the heat given off,

$$H_c = H_r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [1]$$

Let T = temperature of the stream of gases
T_3 = temperature of the outside surface of the gas film adhering to the couple
T_1 = temperature of the couple
T_2 = average temperature of the surfaces surrounding the stream of gases, expressing all temperatures in absolute units

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S = surface of the gas film receiving heat by convection
S_1 = surface of the metal giving off heat by radiation.

Then from the law of heat transmission by convection,

$$H_c = K\,(T - T_2)\,S \ldots\ldots\ldots\ldots\ldots\ldots [2]$$

Inasmuch as with a set of any number of couples the velocity and density of gases are the same for all couples, these two factors are embodied in the constant K. And from the Stefan-Boltzmann law,

$$H_r = r(T_1^4 - T_2^4)S_1 \ldots\ldots\ldots\ldots\ldots\ldots [3]$$

From Equation [1],

$$K(T - T_2)S = r(T_1^4 - T_2^4)S_1 \ldots\ldots\ldots\ldots\ldots [4]$$

The same quantity of heat that is imparted to a unit of the outside surface of the gas film by convection, passes through the film by conduction and may be expressed by the simple equation:

$$H = C\,(T_2 - T_1) \ldots\ldots\ldots\ldots\ldots\ldots [5]$$

therefore $$C\,(T_2 - T_1) = K\,(T - T_2) \ldots\ldots\ldots\ldots\ldots [6]$$

or $$T_2 - T_1 = (K/C)\,(T - T_2).$$

But $$T - T_1 = (T - T_2) + (T_2 - T_1) \ldots\ldots\ldots\ldots [7]$$

or $$T - T_1 = (T - T_2) + (K/C)\,(T - T_2) = k\,(T - T_2).$$

Therefore, for the whole couple,

$$H_c = c\,(T - T_1)S \ldots\ldots\ldots\ldots\ldots\ldots [8]$$

Taking D as the diameter of the couple, then

$$S \propto D, \text{ and } S \propto D + 2\,\delta$$

Equation [4] would then become

$$C'\,(T - T_1)\,(D + 2\,\delta) = (T_1^4 - T_2^4)\,D \ldots\ldots\ldots [9]$$

where C' embodies all the constants.

It should be remembered that the constant C' embodies the convection constant, which is affected by the velocity and the density of gases, and the radiation constant, which is affected by the conditions of exposure of the couple. So when any one of these factors changes the constant must be changed also. It is also probable that the thickness of the gas film changes with the velocity of gases passing the couple. However, the data available do not justify more detailed analysis of the equation. On account of the fourth-power variable, the equation is rather cumbersome to work with. The work can be made somewhat easier by making T_2 equal to unity and expressing the

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other temperatures as ratios of T_2, remembering what this provisional unit is and changing the final results into the standard units. Such substitution of units eliminates one fourth-power factor.

Using this method of arbitrary temperature units and taking $2\delta = 0.08$ in. and $C' = 3.9$, the equation fits the curves A and B of Fig. 6 of the paper. The readings for both of these curves were taken under the same conditions of exposure and with about the same velocity of gases.

For curve R the conditions of exposure and the velocity of gases were entirely different, so the constant C' must be changed. If the constant is made equal to 12, the equation will fit the curve R. The value of $C' = 10.8$ satisfies the curve M.

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No. 1587

DEVELOPMENT OF SCIENTIFIC METHODS OF MANAGEMENT IN A MANUFACTURING PLANT

By Sanford E. Thompson,[1] William O. Lichtner,[1] and Keppele Hall,[1] Boston, Mass.
Members of the Society
and
Henry J. Guild,[2] Bangor, Me.
Non-Member

The authors present in considerable detail the outline of the development of scientific methods as applied to the ordinary manufacturing plant. To make this a more concrete illustration the discussion is centered in the plants known as the Eastern Manufacturing Company, at Bangor and Lincoln, Maine, one of the largest concerns in the country manufacturing writing paper as its final product. The development of scientific methods at these mills, however, is not, as one might assume, descriptive of a simple and comparatively localized industry. As a matter of fact, the processes involved in pulp and paper making are similar in type, so far as management methods — not in specific technique — are concerned, to a vast number of industries.

In the paper are discussed the development of the organization, comparing the old method of control with the new method through its planning department; the progress toward standardization of the making and machining, with the results already obtained; the methods of job analysis, with illustrations describing the standardization of machine and hand processes and the introduction of bonuses; the effect of reduction in working hours; the classification of paper, with balance-of-stores inventories; the effect of standardization and bonus installation in the pulp mill; the method of handling another mill from the one planning department; and the development of the Service Department, with the effect on the personnel of the establishment.

The results secured by the scientific standardization of the various operations in combination with the routing system and bonus plan have effected an increase in production; a decrease in hours; an increase in wages; a reduction in labor cost per ton of production; a saving in materials; an effective control of production throughout the plant; and the development of a spirit of coöperation between the management and the employees.

[1] Thompson and Lichtner.

[2] Superintendent of Paper Manufacturing, Eastern Manufacturing Company.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of The American Society of Mechanical Engineers.

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THE development of scientific methods in manufacturing is being recognized almost universally as an essential to economic management. We say recognized, but this must be qualified by the acknowledgment that in the majority of concerns who accept this as a theory the treatment has been superficial instead of covering the development of plans which are accurate, exact, based on facts, and which account for all variable conditions. An encouraging feature of the situation lies in the fact that the most scientifically managed shops realize that they have by no means reached the ideal. In fact, a truly scientific development necessarily shows up the deficiencies as it proceeds. On the other hand, too many plants are settling back into self-sufficiency after establishing a so-called "Efficiency Department" — a most worthless piece of mechanism as ordinarily conducted — and a "Cost System" which at best indicates how money is lost, and not how conditions can be improved.

SCOPE OF PAPER

2 Nearly all of the published matter relating to the application of scientific methods of management has pertained to the machine shop. In this paper it is the aim of the authors to present in considerable detail an outline of the development of scientific methods as applied to the ordinary manufacturing plant. At the same time, to make this a more concrete illustration, the discussion will be centered in the plants of the Eastern Manufacturing Company at Bangor and Lincoln, Maine, one of the largest concerns in the country manufacturing writing paper as its final product.

3 The development of scientific methods at these mills, however, is not, as one might assume, descriptive of simply a single and comparatively localized industry. As a matter of fact, the processes involved in pulp and paper making are similar in type, so far as management methods — not in specific technique — are concerned, to those in a vast number of industries. The treatment, for example, involves the scientific development and standardization of processes; the job analysis of hand and machine operations; the introduction of planning methods to control very diverse conditions; the systematizing of stores, including supplies, raw materials and material in process; the training of the worker; and the coöperation of the workers with the management through the Service Department and personal relations.

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4 In treating the subject it is proposed after a brief summary and a statement of general principles to take up the plan of control of manufacturing and the methods adopted in the different processes to standardize practice.

INITIAL CONDITIONS IN THE PLANT

5 The plant at Bangor manufactures writing paper of high grade and also operates its own pulp mill, part of the product of which is for use in the paper and a part for sale. The Bangor mills employ some 800 people. A photograph of some of the principal buildings is shown in Fig. 1.

6 The individual processes group themselves into:

1 The manufacture of sulphite pulp from spruce wood
2 The manufacture or making of paper from rags and sulphite pulp
3 The finishing of the paper to make it produce the various finishes required for writing paper.

The manufacture of wooden boxes or cases for shipping the paper also is carried on as a separate department.

7 Before beginning the introduction of the more intimate analyses of the methods and processes, the plant had been brought during the previous two years to a stage much above the average plant of the old type of management in efficient operation. In 1914 it was decided by the directors to introduce scientific methods so as to go down to the bottom of things and develop standard methods of handling materials and labor.

RESULTS

8 The results secured by the scientific standardization of the various operations in combination with the routing system and bonus plan have effected an increase in production; a decrease in hours of labor; an increase in wages; a reduction in labor cost including overhead per ton of production; a saving in materials; an effective control of production throughout the plant; and the development of a spirit of coöperation between the management and the employees.

9 To express the results in another way, scientific management has decreased the time of performing operations about 40 per cent on the average, largely through changes in methods and elimination of waste. A large part of this saving is spent in paying higher wages

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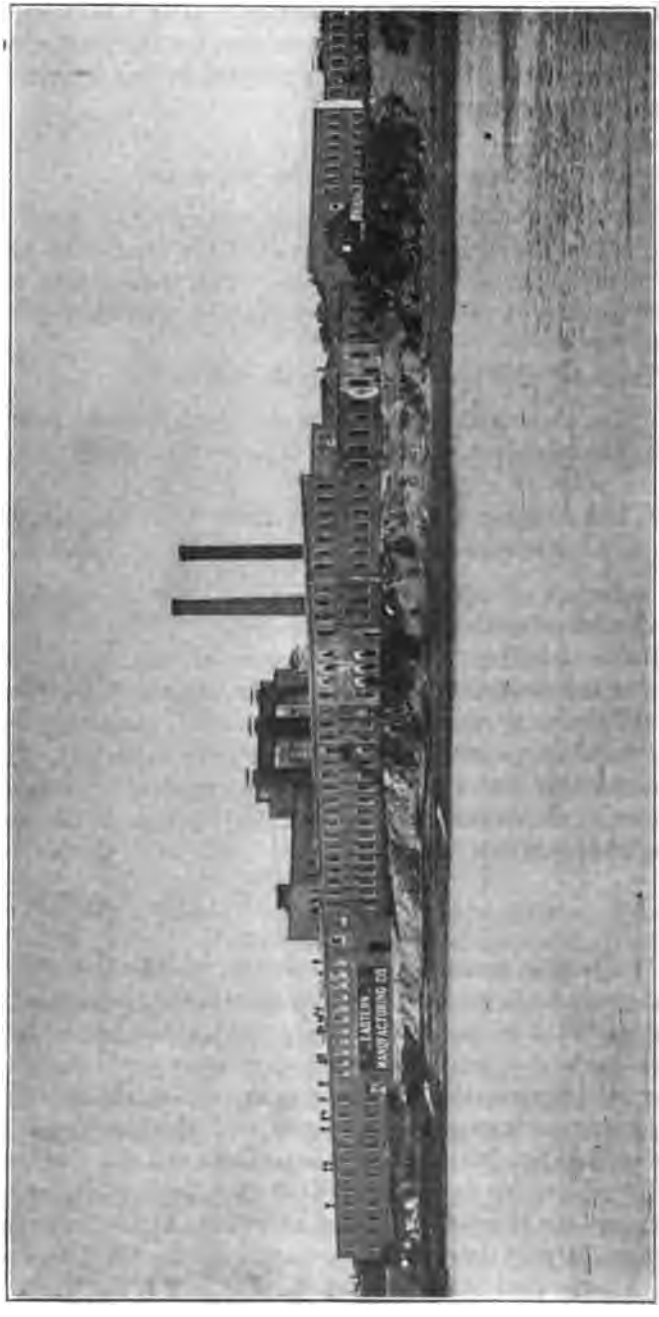

FIG. 1 MILLS OF THE EASTERN MANUFACTURING COMPANY, BANGOR, MAINE

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and in providing more indirect labor, such as is required by the planning room. The company, however, gets the saving in overhead and the profit on the excess production, items of much greater moment than the labor account alone. Thus, through the adoption of scientific methods and with scarcely any overtime, it has been possible during the recent rush period to put through some 50 per cent more paper, and this notwithstanding the fact that before scientific methods were introduced the mill was overcrowded. Of scarcely less importance has been the practicability of largely increasing wages without increasing labor costs per pound of paper. The better planning and sequence of the work through the mill has resulted in obtaining a grasp of the manufacturing problem and a control absolutely impossible of attainment except through planning and routing. The effect upon the personnel of the establishment has been most marked.

THE PROCESS OF PAPER MAKING

10 Paper making today, both in method and machinery, is substantially the same as it was one hundred years ago. It has been carried on during all this time by using traditional methods transmitted from one generation to another. The process consists in brief of beating the "furnish," that is, the raw materials, in a large tub or beating engine, passing this through jordan machines, and then on to the paper machine, after which it is cut and finished by machine drying, or calenders, or by loft drying and plating. The cutting, sorting, and packing have to be done with the greatest care to avoid injury to the paper.

SCOPE OF DEVELOPMENT

11 Scientific management consists fundamentally in finding the best way of doing a thing and putting the plan into execution.

12 The logical process in the development of scientific methods is to begin with the handling, classification, and storage of the raw materials; next establish control of the manufacturing processes, and finally establish by scientific investigation standards of material and standard practice for operating the plant.

13 It is evident that there are two distinct features involved in this: first, the introduction of a system in management, and, second, the establishment of standards. It must be recognized very clearly — and it is because of lack of appreciation of this point that scientific management is confounded with mere mechanism — that system alone is never in itself the goal. System is merely the tool, and a

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necessary tool for control. It is the classification of facts, the job analysis, the intimate study of conditions, that produce the real results in output, in quality, in elimination of fatigue, and in basic coöperation and pulling together between the men and the management. These are principles of general application. The actual work to be accomplished presents in different manufacturing establishments problems singularly alike. The methods of procedure, for example, at the Eastern Manufacturing Company, were similar to those required in almost any plant operating under the ordinary type of management.

DEVELOPMENT WITHIN THE ORGANIZATION

14 In the introduction of scientific management in any industrial establishment it must not be overlooked that by far the most important feature of the problem is the development of a set of principles *within* the organization. It is nothing that can be imposed from without. Unless the management and the workers undergo a change in mental attitude and bring themselves to look at things from a new viewpoint, scientific management cannot exist. The difficulty of attaining the desired end is always considerable. In an old established industry, such as the making of paper, where the methods employed are substantially those which have been in vogue for over sixty years, this difficulty assumes large proportions. The men who act as superintendents and foremen have attained their present positions by absorbing the traditional rule-of-thumb methods that have been handed down for generations and applying them with personal effort and energy. Practically no scientific study of the industry has ever been made. It presents a striking example of a case where opinion has legislated and fact has never been established, where force has ruled instead of law. From these considerations it can be understood readily that the task is no easy one of convincing a group of mill men who stand at the top in their industry, that a scientific study of the art of paper making will make it possible to predetermine exactly the quantity of materials to be used, how each machine is to be operated, the length of time of each operation, and the quality of product which will result.

15 The workers themselves readily coöperate as a rule with the introduction of new methods of management, provided they see that the management is in earnest and is going to see the thing through to a finish. Of course at the beginning questions are raised as to whether the increased output can be produced without working too hard,

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whether the pay will be maintained permanently at a higher rate, and whether there is danger of discharge of part of the employees. With a careful explanation and practical demonstration of results the worker soon perceives that the thing is for his advantage as well as for the benefit of the management. The difficulty invariably comes not from the workers themselves but from the men in the management, including the foremen, who have been accustomed to doing work over and over again in a certain way and hold the viewpoint that because a thing has always been done in a certain way, that must be right, or — which is fully as aggravating — who meet every new suggestion with the claim that "it has already been tried out and failed." Such an attitude is almost inevitable, especially with the older men. Fortunately, in the case under consideration the controlling management was in the hands chiefly of progressive men who were ready to adopt new things.

16 It reflects great credit on the Eastern Manufacturing Company's organization that the men who are now operating the mills under the new methods — the men, in fact, who are carrying on the further work of development along scientific-management lines — are in most cases the same men who were in charge under the old system; some of whom at the outset opposed strenuously and from the most sincere and loyal motives the innovations and readjustments that were necessary.

PLAN OF DEVELOPMENT

17 The work was undertaken in accordance with the following plan:

1 Classify the product so as to eliminate the confusion caused by a multiplicity of trade names and designations for the same article and to permit of keeping a proper balance of stock of the various grades, weights, colors, sizes, and finishes for promptly filling orders

2 Develop a system of routing controlled by a central planning department that will

Insure orders being filled in the proper sequence

Designate the required material for every order

Eliminate wasted time of men and machines by always having a definite job ahead of each operator and each machine; and

Move materials promptly from one operation to another with a minimum amount of confusion and delay

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3 Make a scientific job analysis of every operation to establish standards of materials and standards of operation so as to increase output without undue exertion. Fix rates and bonuses based on these scientific studies that will permit of a largely increased wage to the worker and decreased cost of production through the larger output

4 Develop the personnel of the whole organization — management and employees — to a point that will insure a large measure of coöperation by functionalizing duties, by training, by assuming responsibilities, by recognizing merit, and by encouraging any expression of thought which will facilitate the work in any way whatever.

For clearness of illustration the classification of the product is discussed after the treatment of the methods of control and standardization.

COMPARISON OF OLD AND NEW METHODS OF CONTROL

18 The distinctive difference between the old method and the new lies in the substitution of definite planning for snap judgment. To illustrate this, let us compare briefly the old with the new method.

19 *Old Method.* Formerly, as is common practice in a plant under ordinary management, each foreman controlled the work in his own department subject to more or less erratic calls from his superiors. With a bunch of orders in his file, he assigned the materials, as they were delivered to him, to the various machines or operators under his control, using in general his own best judgment as to the sequence. If material did not come fast enough he would look over his file of orders and chase up the departments through which the work was to pass before reaching him. If, in spite of everything, his work ran short, the employees would all work very slowly, so as to prevent shutting down some of the machines in the department. On the other hand, if work accumulated, he would be up against it to get enough machines or men to do the work, and if these were unavailable, it meant the running of his department overtime with the incident extra expense and dissatisfaction of all concerned. In the filling of orders there was the same old story of broken promises, notwithstanding the best efforts of the Sales Department and the Manufacturing Department, and notwithstanding the fact that the boss finisher was very active and the foremen an exceptionally capable set of men.

20 One great difficulty lay in keeping customers satisfied with

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the deliveries. The Sales Department would receive a telegram from a customer and call the boss finisher on the phone. The latter would go out to the mill and instruct the various foremen to give the order preference. This was almost sure to sidetrack some other customers' orders, who in turn would send in their kicks shortly. With some 500 or more orders in process during the time necessary to make the paper and finish it, with the difficulty from temporarily changing the machines to introduce the rush orders, the personal skill required to keep things straight is evident, as well as the wasted time of men and machinery.

21 *New Method with Its Planning Department.* The Planning Department, centrally located in the Finishing Department Building, now controls in complete detail the progress of each order through the mill. The advantages gained over the old method are manifold and obvious:

a It has placed in the hands of the two men who are responsible for the filling of all orders — the Production Man of the Making Department (formerly assistant superintendent) and the Production Man of the Finishing Department (formerly boss finisher) — absolute control of the sequence in which they shall be run. They decide *when* the work is to be done: the one, when the paper is to be made, and the other, when it is to go through the finishing department

b It affords these production men precise information as to the exact status of any order in the mill at any time without leaving the room

c Each clerk in the planning department has some definitely specified duty to perform and detailed instructions as to just how to do it. There is thus a trained corps of men and women, each an expert on his own job, who are employed in planning in advance the details of each step

d The condition of each department and of every machine or worker in that department as regards supply of work is shown by the Planning Department Control Board and permits the shifting of employees from one department to another, in order to prevent congestion of work or lost time on machines

e It is impossible for anyone to be out of work without the fact being known. In fact, conditions can be foreseen and provisions made to meet them.

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FUNCTIONS OF PLANNING DEPARTMENT

22 The Planning Department performs the following functions:

a It receives all orders from the Sales Department and acknowledges them the day they are received with a promised date of shipment

b It determines the sequence in which jobs are to be run

c It routes each individual order to the machines and work places at which the different operations are to be done, sometimes weeks ahead of the starting of the order

d It makes out in advance the time tickets which will be given to the operators when they are assigned a job

e It keeps each machine and work place supplied with work

f It directs and controls the moving of materials and orders from operation to operation

g It transfers operators from one job to another so that every worker in the mill always has some defined task to work on.

23 It will be evident that any such radical departure from old established methods produced no less than consternation in the minds of these very competent and intelligent foremen. They could not but regard the new plan as stripping them of all authority and relegating them to merely subordinate positions in which their talents could find no place for expression. And it was only after months of patient persuasion by the management, careful instruction, and firm and uncompromising insistence that they were brought to see that the great variety of duties they had been performing were for the most part impositions on them and were in reality diverting them from the main function of their positions, viz., seeing that the work was delivered to them in proper condition, at the proper time, and then properly executed. In reality they had been deprived of any real chance to develop themselves along the lines that would make them of more value to the company and to themselves.

PLANNING THE MAKING OF PAPER

24 The chief aims in routing the materials and planning the running of the different kinds of paper are to (1) produce uniformity of product, (2) reduce number of furnishes, (3) get the paper out on time, and (4) avoid changes on the machines by grouping orders. Careful planning of the runs permits various economies, such as in arrangement of colors, grades, weights, water marks, and deckle widths, to give best results and prevent extensive washing up. For

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example, not merely may whites be run consecutively and colors varied from light to dark, but runs may start with light-weight paper and run up to the heaviest, then the next run start with heavy, working down to light, always arranging, except in very long runs, to bring washups at the time grades are changed.

25 A photograph of the planning department with its control board is shown in Fig. 2.

26 To lay out and follow up the work, the production man of the making department accumulates the different orders for same grade but varying weights, and when enough are ready for a run he puts

FIG. 2 VIEW OF PLANNING DEPARTMENT, SHOWING CONTROL BOARD

them through on a furnish order and fixes a date on which each will be run. He knows from his records, not merely by memory, the time required for running each kind of paper. The orders for a certain kind are grouped and the time required to run the lot is scheduled, always providing a certain leeway to take care of special or important orders that may come in late. From this order of work the production man prepares a schedule or running list for each of the three paper machines. By this means it is easy to provide for rush jobs without the fuss and confusion incident to ordinary methods. At the same time the extra expense of such rush orders is clearly seen, with the result of closer coöperation between Sales and Manufacturing. The running lists are handed to the Route Clerk, who can now

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make out his route sheet, indicating the way in which each order is to be handled; and the "stores issue" can be made calling for the kind and quantity of materials to be used in making each furnish.

27 Individual time tickets for the workmen on the machines, such as are ordinarily used in scientific-management work, are next made out, and placed with the route sheet. They are now ready for the Order-of-Work Clerk to hang on the Planning Department Board under the symbol for the machine or work place designated. When these tickets, properly stamped by the time clock, are given out to the operator either directly or through a pneumatic tube to his department, the recording clerk checks the route sheet for each particular job. This checking of the route sheet, which is sometimes neglected in management work improperly installed, is one of the most necessary features for a proper control of the work. It indicates where each order is, what operations have been done on it, and what remains to be done.

28 Criticism of this accurate planning of the work will doubtless be made by the manager of the old school, who raises his hands in holy horror at the extra employees involved. The fact is, however, that it is cheaper for a clerk to make the entries and designate the order of the work than it is for the superintendent or the boss finisher, as is more usually customary, to write out the same information on a rough sheet of paper, trusting to his judgment or memory, or to a personal notebook, for the information necessary. The proof of the pudding is in the eating. This planning has been one of the important factors in the saving in time and cost of materials.

CONTROL OF THE BEATING OF THE PAPER

29 One of the fundamental processes of paper making is the treatment in the beating engines, which separates the fibers and produces after several hours of beating a mass of pulpy gelatinous consistency.

30 *Economy and Quality Due to Uniformity.* The problem is one of standardization. The importance of uniformity in a process like this, both from standpoints of quality and cost, is little appreciated. The point is this: A product must come up to a certain standard. In paper, for example, Government orders not only specify quality but require that the paper pass definite tests, with a penalty for failure to maintain this. Now if the process is inexact, as most manufacturing processes still are — the variations in beating, the variations in the relative amounts of ingredients, and the variations

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in moisture in the raw materials which affect the net weights make it necessary for the manufacturer to err on the safe side. This means beating long enough to allow for the worst conditions, and using enough of the most expensive ingredients so that every batch will pass muster. Consequently, the average time of beating and the average amount of the most expensive ingredient must be away above the required standard. Money is thrown away in material and the quality is irregular. If, on the other hand, the variations are eliminated and uniformity strictly maintained, the average times and quantities may be maintained very close to the standard, and not only will there be immense savings where the raw materials are expensive, but the quality will be more acceptable to customers because of greater certainty of uniformity.

31 *Standardization of Beating.* For the past hundred years the furnish has been proportioned by the individual judgment of the paper maker; and the amount of beating has been determined by the beater man chiefly by "feel" of the stock, with a resulting difference of some 20 to 50 per cent in the time required by different men or by the same man, according to his humor. The standardization involves, then, primarily a study of materials and secondarily the fixing of a standard practice. No attempt has yet been made to change radically the machinery or the process. The strength of the product resulting from the beating is dependent upon the length of time and manner of beating the fibers, which is controlled by the set of the beater roll. The variables which had to be considered and studied in the making of paper are as follows:

1 Control of amount of bone-dry stock put into beaters
2 Control of density of stock, that is, the percentage of water
3 Development of proper method of beating for maximum strength, this being dependent upon set of beater roll at start and the varying of beater roll during the process of beating
4 Development of proper methods of testing for
   a Density
   b Fiber length
   c Fiber strength
   d Slowness
   e Set of beater roll
   f Hand sheets
   g Velocity of stock in beater
   h Strength of each of the raw materials

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5 Determination of relation between proper method of beating and proper method of jordaning and of running on paper machine.

32 The endeavor to standardize all these things at one operation would mean a corps of at least a half-dozen thoroughly trained men, whose services probably could not be obtained, and three to five years of solid work, not to mention the large amount of money required to finance the proposition. In view of these considerations it was decided to do things on a smaller scale, so the investigation was limited, for a start, to the beating alone; and by means of following the stock on to the jordans and the paper machines and by taking tests off the end of the machines, it was possible to proceed with the investigation, as outlined.

33 What, then, is the problem? The problem is to use the beater without any change whatever in its construction, to standardize the raw materials which go into the paper, and to standardize the operations. In other words, we expect to get identical results provided we use a definite quantity of rags, a definite quantity of wood pulp of a definite strength, definite quantities of alum, size, glue, gum, etc., each passing certain standard specifications, and mix these ingredients in a definite way.

34 The difficulty in this proposition is in getting each of the ingredients going into the beater to contain the same amount of bone-dry stock per unit of volume. This seems a very simple matter but in reality is very difficult to bring about. Gross weights of pulp and rags are easy to obtain, but to determine the percentage of moisture special centrifugal apparatus had to be developed and a well-defined system of taking records. The accomplishments have well warranted the labor. Through the investigations of these various conditions it is possible at the present time to know what is actually going into each furnish, both as to percentages of raw materials and density, and to fix definite times of beating. With the aid of the information already obtained, more intimate investigations are being continued with a view to still more definite control of the processes and the beating engines. In somewhat similar fashion the sizing has been standardized. Through the accurate adjustment of furnishes and size, a marked saving has been made in cost of materials.

INCREASE IN OUTPUT OF PAPER MACHINES

35 During the period while the investigation was being made on the beaters, it was found advisable to increase the output of the paper

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machines. This could be accomplished in three ways: (1) by increasing the speed of the machine, (2) by widening the sheet on the paper machine, or, as it is technically known, increasing the deckle width, and (3) by reducing the number and length of shutdowns through better planning of the orders.

36 To establish correct speed standards, past records were tabulated showing the speed of the paper machine for each kind of paper run on the machines. It was found that with the same furnish the speeds of machines at different times would vary as much as 50 per

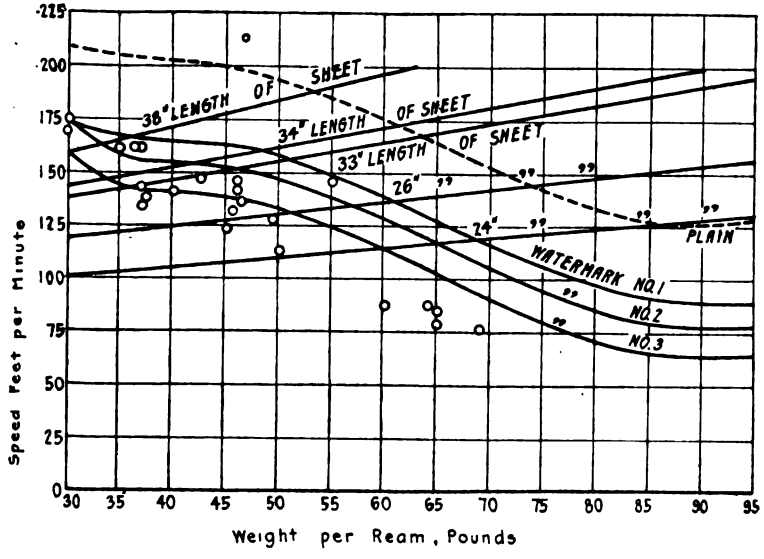

FIG. 3 SPEEDS OF PAPER MACHINE FOR A CERTAIN GRADE

cent. This variation in speed was caused sometimes by variation in the condition of the stock, and particularly by the lack of uniformity.

37 As a result of this study and through the partial standardization of beating, definite speeds for certain grades of paper were established for each furnish, and were specified to the men on the machines with each order. In Fig. 3 are shown the curves for one kind of paper for different weights of stock and different watermarks. For uncut paper the standard speeds are indicated by the curved lines. If the paper is cut at the end of the machine into sizes indicated by the straight lines, the speed is limited by the length of sheet

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cut off as well as by the weight. Then the speeds for plain paper cut into sheets 34 in. in length would follow the dotted curves until they reach the straight line marked 34", and then follow this straight line. For example, 50-lb. plain paper of this grade would be run at a speed of 195 ft. and 70-lb. paper at 180 ft. Before fixing these standards there was no definite relation between speed for different weights. It was found possible to increase the speed as much as 30 per cent — and sometimes more — over the average of the old speeds. The small circles on the diagram show the variable speeds before standardization.

38 Another big factor in the saving of dollars and cents was the forming of a sheet of paper off the end of the machine which would not be appreciably overweight. Paper is bought on the specification, for instance, that 500 sheets of 24-in. x 36-in. should weigh 80 lb. This assumes, however, that the weight can vary 2½ per cent either way of the 80 lb. Therefore, any sheet taken off the machine which will give just a weight of 80 lb. for 500 sheets will bring just as much money as a sheet 2½ per cent overweight, or 82 lb. If the sheet, on the other hand, is more than 2½ per cent underweight, the paper is sold by actual weight. The uniformity in weight also makes it more acceptable to the customer. Besides this, the paper has certain qualifications in the color of the sheet, the rattle, tear, etc., all of which can be affected by the machine man.

39 By studying conditions and standardization it was found possible to obtain more uniform and normal weights. To maintain these characteristics of weights and quality at a high standard, a bonus was outlined for paying the machine tender and his assistant according to the saving which they made on these various factors. In Fig. 4 is shown the actual record of variation from the limits specified to the machine tender and the bonuses earned. Formerly, the majority of paper had been run overweight and with large variations. To figure the bonus for the week the sum of the weights between each set of lines is found, and multiplied by the factor 1, 2, or 5. The "fors" are added and the "againsts," and the per cent of the bonus earned is the total sum of the "fors" divided by the "fors" plus "againsts." In the example shown, the bonus earned is 95 per cent of the maximum, or $3.60. In addition to this bonus is another of $3.00 per week maximum, based on production.

40 Further increase in the output of the machines was found practical from time to time by increasing the deckle width. The number and length of shutdowns of the paper machines have been

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reduced through more careful planning of the runs to avoid changes.

41 In describing the work of the Planning Department, reference has been made already to the routing of the Making Department. As is there stated, as soon as the running list of orders for the paper which is to be run during the next week, two weeks, or even a month ahead, is scheduled, the entire work is routed and all tickets made out for each run of paper. The route sheet shows when to fill each beater, how long to beat, when to dump, and the time when the stock

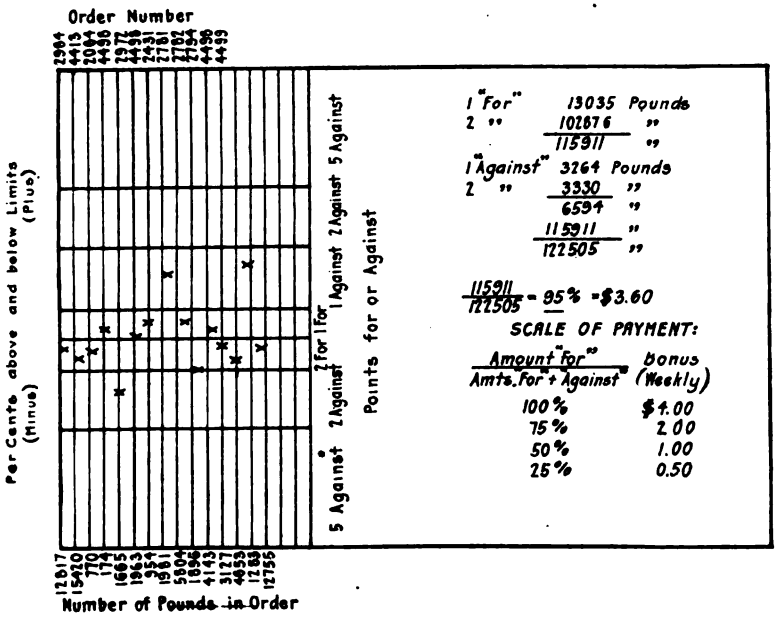

FIG. 4 WEIGHT BONUSES ON PAPER MACHINE

will start on the paper machine and be finished. The whole thing is tied in for quantity and quality of product. Since the development according to more exact methods, the quality of the product has been greatly improved, especially in respect to uniformity.

CONTROL OF THE FINISHING DEPARTMENT

42 The Production Man of the Finishing Department controls the orders after the paper is run off the paper machine. From the Production Man of the Making Department. whose desk adjoins his

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own, he obtains the date on which the paper for each order will be run on the paper machine. He then consults the list of the various orders which are in progress or slated, and, knowing the time required for each, he determines when the order in question will be finished and the date and destination of the car in which it will be shipped. The list of promises for the various orders is sent to the Sales Department and each order is entered in the Car Promise Book, which is kept in the Planning Department, under the date and destination given. With the acknowledgment of the customer's order goes the promised date of delivery. This Promise Book is one of the most important features of the plant in its effect upon the delivery of orders. On the very day on which the order is received, it is assigned its place in the running list and (on paper) loaded in the car in which it will be shipped, possibly weeks or months later. The Promise Book shows at all times the amount of goods assigned to each car. When the capacity of a certain car for a certain date to a certain destination has been reached, either an additional car is provided for the same date or the remainder of the shipment is promised for the next date on which a car for the required destination is to go forward.

43 In case a special rush or some other cause makes it necessary to change the date of running the order in question over the machine, the Production Man of the Finishing Department is notified of the change, the reason for it, and the new date of running the paper. If this necessitates a change in his promised date of delivery, he notifies the Sales Department and the customer of the change and the reason for it, and alters the order in the promise book to conform to the new date. It will be seen that the method described affords a means of tracing all orders with a view of shipping on time.[1]

44 After the promises have been made and the orders listed, they are sent through the various divisions of the Planning Department that work on the Finishing Department orders. Here they are routed and the tickets and material issues made out in a manner similar to that described for the Making Department, so as to have everything ready in advance of the time when the paper comes off the paper machine ready for the Finishing Department.

45 *Control Board.* The Planning Department Board, which is illustrated, together with the time stamp and pneumatic tube, in Fig. 5,

[1] During 1916 the demand for paper was so excessive that uniform control was less possible than in normal seasons and many orders had to be delayed in shipment to adjust the supply to different customers. Since January 1, 1917, however, the control as outlined has been definitely lived up to.

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shows the location of every order in the factory, gives the time required for the job, and provides almost automatically for the sequence of work. It thus insures continuous work for every man or machine or else shows the reason why.

46 By this system the time tickets are made out by a clerk instead of by the operative, but this saves the time of the operative, reduces errors, and permits making carbons which can be used for inspection tickets, move tickets, etc. In some cases, also, brief instructions can be placed on the time tickets. The advantage of this

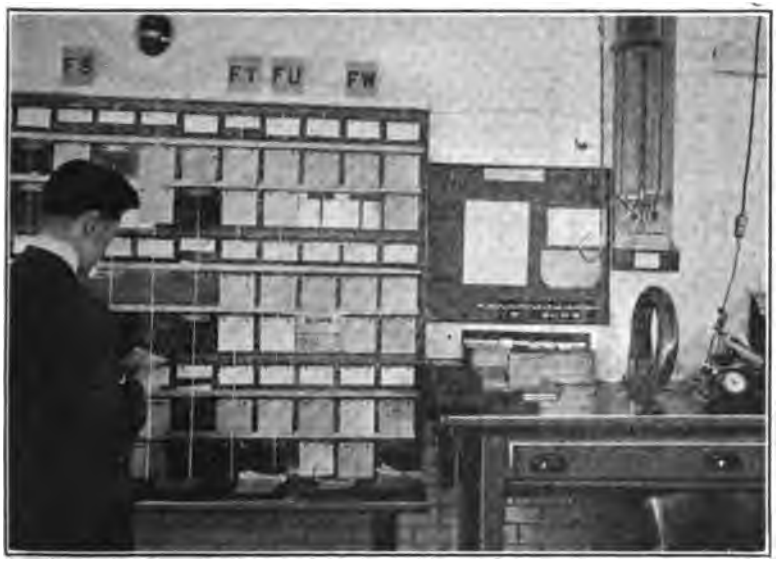

FIG. 5 CONTROL BOARD

system of individual tickets is evidenced by the fact that many plants handling the most intricate and detailed work are using them with good results.

47 *Shop Ticker Boards.* For the information of the instructors, workmen, and move men, Shop Boards (shown in Fig. 6) are located conveniently to the departments which they affect. There is a space on these boards for every machine and work place in the department. The order-of-work clerk posts tickers on this board at the same time that he posts them on the "ready" hooks of the control board, and in the same sequence.

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JOB ANALYSIS

48 Before starting the detail work of time study, a careful examination was made of the physical arrangement of each department. In certain cases, machinery was changed to new locations to facilitate access, afford storage space for orders, obtain better light, and relate the departments to each other in a better manner. Frequently,

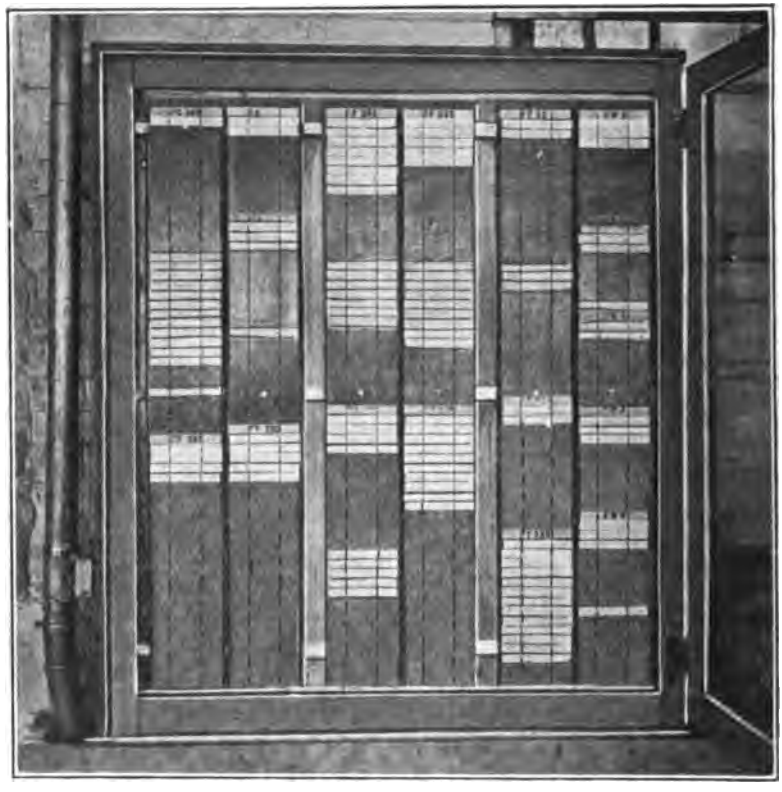

FIG. 6 SHOP TICKER BOARD

however, the necessity for changes such as these does not show up until after the detail study and analysis of the individual jobs.

49 The establishment of a system of control of materials and orders through the Planning Department as described, is usually necessary before effective work can be done in connection with the detail study of the operations themselves. We must have a definite supply of materials, a proper sequence of work, and a means for recording the time taken on the various jobs.

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50 The taking of time studies does not consist, as is sometimes assumed, in simply recording the time in which an operation is being performed, nor even in finding the times on the unit operations of which it consists. A time study made in this way is valueless from a scientific standpoint. The purpose of time study is not to find out the time in which a piece of work is being done nor even the quickest time in which it is being done. It is to find out the best method of performing each unit division of a given operation; to pick out any operations that can be eliminated; to differentiate between the quick methods and the slow methods; to find out the proper sequence of performing the unit operations; and, in short, having determined these various factors, to establish the best methods as standard practice. Too often time study is looked upon simply as a means of rate fixing, and rates are set not in accordance with the way work should be done but simply in accordance with the way work is being done.

51 In order, then, to establish standards by which piece rates may be set, or bonuses fixed, a thorough analysis of each operation is necessary — an analysis in which the stop watch is used as one of the tools for reaching the proper determinations. Job analysis involves the investigation of existing methods and the scientific development of standards. To illustrate best the method of standardization, one of the operations in the Finishing Department, that of trimming paper, will be taken up in some detail.

STANDARDIZATION OF TRIMMING PAPER

52 The manner of performing the various operations in the Finishing Room — and this is true also in almost every manufacturing plant — has developed partly as a result of personal judgment and opinion and partly from rules laid down by the management based on investigations which cover only part of the conditions. They do not scientifically treat the problem as a whole from the viewpoint of reduction in waste of materials, economical use of machines, and reduction in overhead charges and time of labor.

53 Whatever the industry, such conditions as these are typical, and a description of the method of developing standards in this class of work will illustrate the general plan which has to be followed.

54 All paper after it has been finished is trimmed to an even size by making cuts on all four edges. The work is done by placing a certain amount of paper on the table of a trimming knife, squaring it up against a gage, trimming one edge, then turning the paper about,

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setting the gage, trimming a second edge, and so on until all four have been trimmed. The operation is shown in Fig. 7.

55 It is apparent that one great factor in the economy of this operation is the amount of paper that can be trimmed with one cut of the knife. A scientific study was made of just how much of each of the different kinds of paper could be cut at once without damaging the stock, and the thickness of the knifeful prescribed for each. The proper sequence in which the different edges should be

FIG. 7 TRIMMING PAPER

trimmed in order to expend the minimum of time and effort was also determined. The amount of paper a man could lift from the truck to the trimming table and from the trimming table back to another truck without strain or undue fatigue on him, or danger of cracking the surface of the stock, was also determined. The curve indicating the amount of paper per lift is shown in Fig. 8. The small amount below the 35-lb. weight is due to the lightness of the paper.

56 When the results were finally obtained, it was found that the amounts that could be accurately cut varied with different kinds and weights of stock from less than 3 in. to about 5½ in., the maximum that could be placed in the machine.

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57 An illustration of the necessity for constant care, even with the best management, is shown by the fact that after the trimming and subsequent operations had been operating under standard methods for over two years, a slip-up occurred through an unauthorized change in method of sorting which resulted in a few shipments of imperfect paper.

58 *Time Studies.* Not until these standards of handling had been developed could the studies of time be utilized, although in connection with the standardization some time studies were needed for comparative purposes.

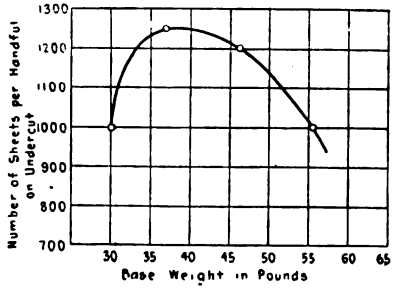

FIG. 8 NUMBER OF SHEETS PER LIFT FOR TRIMMER

59 When making time studies the matter is first taken up with the operator, and he is invited to coöperate with the time-study man for the purpose of establishing conditions of work which will be satisfactory. Detail times are taken of the unit operations, the data are thoroughly analyzed, and the units are recombined. The results of a study such as is required on paper cutting can be best illustrated by a table showing the unit times in one set of operations, such as Table 1. The standard time for any job on this particular paper stock is obtained by combining these units.

60 Having determined not only the unit times but the allowance necessary for delays and resting, the time for doing the work is fixed. The next step is to make out instruction cards giving details of each move to be made and the time allotted for each.

61 *Introduction of Standard Methods.* Having established standards for this trimming operation, one operator was selected and started on the new methods. He quite naturally did not like to be called upon to try to trim a considerably larger quantity of paper in a day than he had previously done. He was assured, however, that

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the job could be done as outlined, and under the close supervision of the man who had made the time studies he tried out the job and eventually, though much to his surprise, found that because of the improved methods it could be done. Little by little and step by step

TABLE 1 UNIT TIMES FOR TRIMMING PLATER STOCK, IN MINUTES AND DECIMALS

(21×33–24×36)

Operations	Place stock on machine, per knifeful		Square stock 4 sides, per knifeful		Square stock and cut 2 sections, per knifeful			Place stock on truck, per knifeful		Chg. jobs, per job
	1 lift	2 lifts	Very high edge, 7 cuts	6 cuts	5 cuts	8 cuts	6 cuts	1 lift	2 lifts	
Standard task times	0.39	0.67	2.77	2.46	2.16	3.07	2.47	0.58	0.81	3.00
Total net times	0.27	0.46	1.91	1.70	1.49	2.12	1.70	0.40	0.56	3.00
a Walk from machine to truck	0.03	[2]0.03	.....	.....	.....	.....	.....	.....	.....	.....
a Get stock in hand	0.09	[2]0.07	.....	.....	.....	.....	.....	.....	.....	.....
a Place on machine	0.08	{0.08 / 0.04	.....	.....	.....	.....	.....	.....	.....	.....
b Remove board	0.07	[2]0.07	.....	.....	.....	.....	.....	.....	.....	.....
g Set gage back 1st trim	.....	.....	0.09	0.09	0.09	0.09	0.09	.....	.....	.....
g Set gage back	.....	.....	0.06	0.06	0.06	0.06	0.06	.....	.....	.....
g Set gage forward	.....	.....	0.06	0.06	0.06	0.06	0.06	.....	.....	.....
g Set gage before cut	.....	.....	[1]0.05	[4]0.05	[2]0.05	[2]0.05	[4]0.05	.....	.....	.....
h Push stock to gage	.....	.....	0.03	0.03	0.03	0.03	0.03	.....	.....	.....
s Place pads	.....	.....	[1]0.04	[4]0.04	[2]0.04	[1]0.04	[2]0.04	.....	.....	.....
c Trim stock	.....	.....	[1]0.06	[4]0.06	[2]0.06	[2]0.06	[4]0.06	.....	.....	.....
d Discard waste	.....	.....	[1]0.03	[4]0.03	[2]0.03	[2]0.03	[4]0.03	.....	.....	.....
Turn stock 90 deg.	.....	.....	[2]0.07	[2] .07	[2]0.07	[2]0.07	[2]0.07	.....	.....	.....
Turn stock 180 deg.	.....	.....	[2]0.09	[2]0.09	[2]0.09	[2]0.09	[2]0.09	.....	.....	.....
t Remove pads	.....	.....	[2]0.03	[2]0.03	0.03	[2]0.03	0.03	.....	.....	.....
g Run up gage — remove stock	.....	.....	.....	.....	.....	.....	.....	0.09	0.09	.....
p Get stock in hand	.....	.....	.....	.....	.....	.....	.....	0.11	[2]0.09	.....
p Carry to truck	.....	.....	.....	.....	.....	.....	.....	0.04	[2]0.04	.....
p Even stock on truck	.....	.....	.....	.....	.....	.....	.....	0.09	[2]0.07	.....
Discard bottom sheet	.....	.....	.....	.....	.....	.....	.....	0.07	0.07	.....
Change instruction card	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.25
Read instructions	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.75

[1] Multiply by 7
[2] Multiply by 3
[3] Multiply by 2
[4] Multiply by 6
[5] Multiply by 5
[6] Multiply by 8

he acquired confidence in the instructions given him. He was undergoing a change in mental attitude and coming to look at his job from an entirely new viewpoint. He finally arrived at the stage where he frankly admitted that his conception of his job and the practice of years were very inferior to the detailed instructions now given him,

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and he was willing to try to do anything suggested, with the keenest interest and confidence in the outcome.

62 *Bonus.* The incentive for a man to do a piece of work as prescribed on his instructions and to do it in the time allotted to him lies in giving him a remuneration in excess of what he can earn under ordinary day pay. This remuneration is best given in the form of a bonus. In the present case a bonus of 35 per cent was given. This means that if a job is accomplished in the allotted time of, say, 2 hours, he receives his regular day rate for the two hours plus a bonus amounting to 35 per cent of his wages for this period. If he fails to accomplish it in the allotted or standard time he still receives his regular day pay with no reduction. Today the particular man first started on this trimming, and who is sixty-five years old, practically never loses a bonus. He is earning 35 per cent more money than he ever earned before, and admits that at the end of the day he does not feel any more tired than he ever did when working under the old system. More than this, he states that there is to him a great satisfaction in having done a big day's work and having done it well. The first step is always the hardest. As soon as one man in a department succeeds in accomplishing his task and earns large wages, the others immediately become interested and clamor for a chance to do the same thing; and they start in, knowing that it actually is being done by someone else and hence is possible of accomplishment.

63 In this department, under old methods, seven machines were required to do the work, and frequently the department worked overtime. After all the work was put on task and bonus, four machines easily handled the same amount of work with no overtime and the operators were transferred to other work until again required to take care of the increased production.

INSPECTION

64 The establishment of bonus work has been accompanied by a close and rigid inspection. No work is allowed to pass that is not up to a high standard of quality. Unless the work passes inspection, the bonus is not allowed. Any defects in previous operations that make it difficult to perform the present operations are almost sure to be detected, for work is supposed to come to each operator in good condition, and if it does not do so, he is the first to notice it and demand a time allowance on his task. Each man's task thus becomes a check on the various operations preceding it.

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EFFECT ON WORKERS

65 The foregoing description is typical of the work done in all divisions of the Finishing Department, and has been dwelt on in detail in order to clearly illustrate the methods that have been followed throughout. Particular attention is called to the effect on the workers. In most cases, they have been given an entirely new conception of their jobs. They have been taught the best possible way of doing their work, and take pride and satisfaction in doing it well. Their earnings are large, and the tone of the whole organization has been raised.

STANDARDIZATION OF PLATING PAPER

66 One other case will be cited, where the conditions are quite different and where the operators are women instead of men. The plating of paper is the operation which produces the linen finish so popular in writing paper, and is accomplished by piling up sheets of paper with alternate sheets of linen cloth and occasional sheets of zinc, and running this through a roll press. Different types of finish require different arrangement of sheets, different linens and different numbers of sheets. The plating is done by a gang of 24 girls, more or less dependent upon each other for output. The gang works in groups of three girls each, who are absolutely dependent on each other for production. The operation is shown in Fig. 9.

67 After the studies had been made on this job and the instructions prepared and the rates set, no one in the organization who was supposed to know anything about plating believed that the tasks were possible of accomplishment, nor did they have the least hesitancy in saying so. More than this, there were questions raised as to whether paper plated in the manner prescribed would be fit to use after it was done. The opinion of the superiors was reflected in the attitude of the workers; and we were confronted with the proposition of tackling 150 girls and women — all predisposed in this way against the new methods — and convincing them that the work could be done as outlined. Nor was there any chance of taking them one by one as in the case of most other jobs. The smallest unit in which they could be handled was one plater, or twelve girls. This job is done on piece work, and in spite of the fact that the rates were set so that the girls could earn a very much larger wage than they had been receiving, they were so convinced that the work could not be done as intended that it was over a year after they had been started before they were able to attain to the standards set. During this period they were instructed daily,

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encouraged for good work, and reasoned with when they became careless or discouraged. Frequently one plater would show marked progress and do very well on one particular finish and then fall down badly when a different kind of finish was assigned. Eventually, however, the girls became familiar with all the different finishes and realized the fairness of the rates.

68 These girls, many of whom at the beginning found it difficult to earn enough even to average their former weekly wage (they were paid their minimum weekly wage whether or not they earned it by

FIG. 9 PLATING PAPER

their piece prices) are now averaging a great deal more than this. The output of the department has increased greatly and the labor and machine cost, notwithstanding the large increase in wages paid, has been reduced by a large percentage because of this increase in output.

REDUCTION IN WORKING HOURS

69 In January 1916 the management of the company decided to reduce the working hours of the entire Finishing Department from 55½ hours to 50 hours per week, and to raise all rates so that the earnings for the 50 hours would be equal to those paid for the longer time. Although business had not at that time recovered from the recent depression, this decision was reached notwithstanding the knowledge

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that through limitations in machines the labor cost in at least certain cases would be increased.

70 Like almost all examples of reduction in hours, it is difficult to separate the effects of this from the effects of other conditions. In one department, however, working on piece work fixed by scientific job analysis, a fairly definite conclusion may be drawn. The curve in Fig. 10 shows the earnings of the girls before and after the reduction in hours. From a study of the curve and knowing the conditions in the shop, it is fair to estimate an increase of output per hour of about 10 per cent, due to the shortening of the hours. In this estimate the curve for the latter part of 1915, which would indicate a much larger increase, is disregarded, and the relation is taken between the middle period of 1915 and the year 1916. It will be noticed that there is a gradual increase in production as soon as the hours were shortened, and after about six weeks a period of slight further increase. Records beyond the last date given by the curve show substantially uniform returns, that is, a nearly horizontal line.

71 It must be understood that this does not in the present case represent a reduction in cost, because the piece rates had been increased. It does indicate, however, that in the shorter day the girls actually accomplished the same amount of work as formerly with the longer hours. Furthermore, because the girls did an equal quantity of work per day the overhead charges, which are always a large item, were not increased.

CLASSIFICATION OF PAPER

72 In analyzing the affairs of any manufacturing establishment producing a great number of articles, or a great number of varieties of the same article, the management engineer is always confronted with the lack of any systematic classification of the product. It frequently occurs that no list of the different items can be found, and but very imperfect records of the sales of each.

73 This company makes a great variety of grades of paper in many different colors, sizes and weights. The varieties were known sometimes by grade, sometimes by watermark, and often by the customer's trade name. There was no existing classification, and while the mill officials themselves seldom became confused, owing to their acquired familiarity with the product, it was necessary to standardize the names or designations of the product before the prod-

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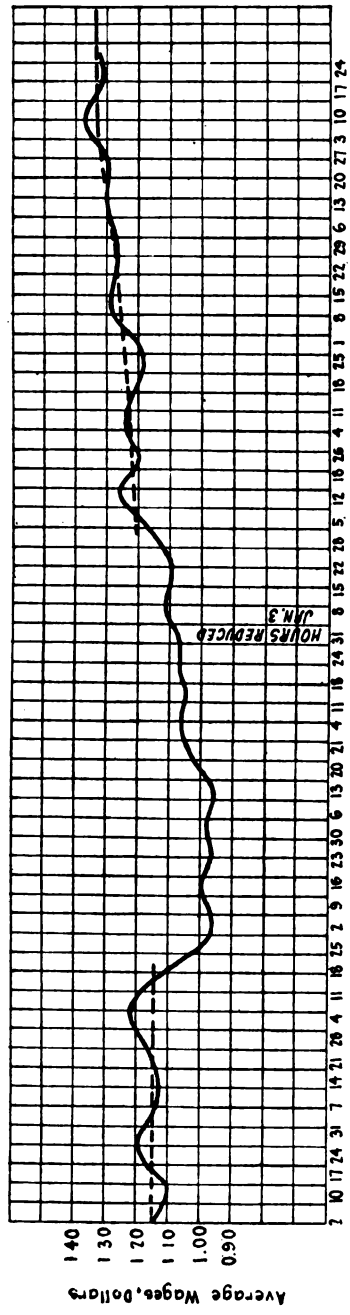

FIG. 10 EFFECT OF REDUCTION IN HOURS ON EARNINGS OF PLATER GIRLS

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uct itself could be standardized. A mnemonic-symbol system was devised and is now in general use. By means of the symbol the grade, base weight, color, size, and finish of any paper is clearly indicated. Incidental to this work, valuable information concerning the variations in grades, etc., was secured.

74 *Collecting Data.* In developing the symbol classification it was first necessary to accumulate all of the names by which the different papers were known, next to separate these into grades, then to ascertain the different colors in which each grade was made, and finally the different finishes which might be given to each. The distinction as to the grade was made from the "furnish," that is, the various ingredients and the quantity of each from which it was made. All papers having the same furnish were of the same grade.

75 Four hundred different designations of product were collected. These were classified into 125 grades and these further divided into seven general groups: Bonds, Envelopes, Flats, Ledgers, Linens, Maps, and Varieties, the last being composed of about twenty grades that could not be placed in any of the other groups. There were 45 different colors and 35 finishes. The mnemonic symbols were devised as follows: the first three letters indicated the grade; the next two, the color, and the last two, the finish. Between the grade letters and the color letters were written three figures giving the base weight of the paper, and between the color letters and the finish letters was a series of figures giving the size and ream weight of the paper; thus, the symbol PBC462EB172220PC stands for Edgars Blue Cascade Bond Paper, 46.2 lb. base weight, crash plated finish, size 17 in. × 22 in., ream weight 20 lb. Interpretation of mnemonics is as follows: P — paper; B — bond; C — Cascade; 462 — base weight in pounds, the last figure always being considered as a decimal; EB — Edgars Blue; 1722 — size of sheet, 17 in. × 22 in.; 20 — weight of ream, 20 lb.; P — plated; C — crash finish. This symbol, although lengthy in appearance, only contains seven letters in addition to the figures which are necessary for giving the weight and size, and by its use avoids writing out at least as many words as the number of letters. Since each letter is selected to bring the word which it represents to mind, usually the first letter of the word being chosen, it is easy to interpret at a glance any symbol which may be devised.

76 *Reduction in Number of Grades.* In analyzing the collected varieties with a view to properly classifying them, it became apparent that there were a great many supposedly different grades that did not differ at all. In other words, the lack of any proper classification of

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product had resulted in a great deal of ignorance concerning it. Further study of the matter revealed the fact that the distinctions between some of the grades were so very finely drawn that there was no value in maintaining them; that the furnishes could be made identically the same without in any way changing the results.

77 If this condition existed as to grades, was not the same or a similar condition likely to exist as to color and finish? Here were other matters to be carefully analyzed from the making standpoint. Investigations are now being conducted with a view to eliminating needless distinctions and reducing the variables to the least possible number.

78 *Determination of Amount of Stock to Carry.* The stock of paper to be carried in order to fill orders promptly and at the same time not to tie up too much capital in this stock was a matter of great importance and required very careful study and investigation. The results accomplished have been:

a A large reduction in the amount invested in stock
b A standardization of the quantities of each item to be carried
c An arrangement of the stock house that permits the quick and easy location of any item desired. This has greatly reduced the amount of time and labor that was previously necessary to secure stock for filling orders.

There were two general classes of stock carried:

a Eastern stock. This consisted of ream packages of the different sizes, weights, and colors of each grade that were made to supply the general trade
b Stock "Holding." This was the designation applied to stock packed in cases which had been made on customers' orders and which was being held for future delivery upon notification.

79 The determination of amount of each stock to carry had been based on the judgment of the superintendent and boss finisher. When orders were scarce, it was the custom to run orders for stock rather than to shut down the machines, and the requirements as to what classes of stock to make had never been a matter of analytical study based on past sales over a given period, taking into account known seasonal fluctuations. The first step toward a more scientific determination of this required a rearrangement of the stock house.

80 *Stock House.* The storage of finished stock was complicated

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greatly by the large number of kinds and grades of paper. As stock had accumulated, the aisles had been filled. When it was necessary to get out stock, a man with a flash light climbed over the piles of stock and hunted for the item needed. The stock records were incomplete and the location of any particular item only known when some one happened to remember where it had been placed. The congestion and overflow into the aisles prohibited the use of the motor truck designed for the cased stock, so that cases had to be removed by dragging them over each other by hand or by some contrivance rigged up with block and tackle.

81 *Study of Conditions.* Before attempting a physical rearrangement, it was necessary to determine exactly what items of stock should be carried, how much of each should be ordered at a time, and how low the amount of each should be allowed to drop before it was replenished; and to devise a balance-of-stores system by which an exact record of every item would be carried under its mnemonic symbol and be available for instant reference. The sales records for a year previous were carefully scrutinized and exact data as to the amounts of all items sold were secured. A study was made of the then existing demands and the known seasonal fluctuations that would affect certain grades. From the information thus obtained, a decision was reached as to the minimum to which each item on the stock list should be allowed to drop before replenishing, and the amounts to order when this point has been reached. The "Minimums" and "Amounts to Order" were set with a view to holding the amount in stock down to the lowest possible point that would still permit filling orders promptly.

82 *Balance Sheets.* Worked Materials balance sheets were made for all items. These contain the record of every transaction in each item of stock carried. All Issues and Materials Received tickets pass through the hands of the Balance of Stores Clerk, who keeps these records and makes the entries. When the quantity of stock available falls to the amount indicated as a minimum, the Balance of Stores Clerk issues an order for the amount of paper to be made. No order for stock can originate from any other source. The balance sheets are under constant surveillance. When sales increase or decrease, the fact is noted, and this affords a means of keeping the minimums and amounts to order correctly adjusted to both the requirements of sales and the policy of carrying no more stock than is necessary.

83 *Economies Effected through Rearrangement of Stock.* The

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actual rearrangement of the stock was next undertaken. In the case of Eastern stock this necessitated the removal of all stock and sorting it into separate items. Steel racks for the storage of the ream packages were installed, divided into tiers, so that no pile of packages was more than three feet high. A space for each item sufficient to hold the maximum amount was assigned to it, and all were arranged alphabetically according to symbols. Each item was piled in the proper space and a "Worked Materials" tag for every order of each

FIG. 11 REARRANGED STOCK HOUSE WITH ITS RACKS

item made out and inserted with the order. Whenever any of it is removed, a deduction from the amount is made on the tag. A view of the interior of the stock house showing the racks is given in Fig. 11. In rearranging the cased stock, a number of disclosures were made. There were cases of customers' stock that had been made years before and become obsolete. There were cases that had been made on customers' orders and never been ordered out. There were many cases for which there were no existing records. There was enough stock of some items to keep customers supplied for from two to six years at the rate at which they had been using it.

84 Obsolete stock was removed; customers were notified that deliveries of holding orders would be made, and the stock for each customer was assigned a place in the Stock House. No cases are

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allowed to remain in the passageways or aisles over night, so that they are always kept open for easy access to the stock. At the end of each row of cases a card is kept, on which is entered the number of each case as it is stored there together with its location in the row and its contents. When cases are removed that fact is noted on the card.

85 *Advantages Secured.* The advantages secured by this classification and arrangement of stock are as follows:

a The amount of stock in Stock House when work was started was equivalent to 4800 cases of 500 lb. each; the new method insures there never being more than the equivalent of 2800 cases. This is a reduction of upwards of 40 per cent, or one million pounds of paper

b The Stock House which was considered too small to contain the amount necessary to be carried is now ample

c The work of handling the stock which was previously done with a force of nine men, helped out on occasions by one or two additional, is now easily handled by five, who, in addition to their regular work, pack all shipments to be made from Eastern stock.

SYSTEMATIZING OF GENERAL STORES

86 It would be practically a repetition in substance of what has just been written to go into details of the work done in the company's general storeroom for miscellaneous and mill supplies.

87 The following features were introduced:

a A mnemonic-symbol classification and a balance-of-stores system by which articles were automatically ordered when they had fallen to a prescribed limit, and by which the amount of stock on hand was held down to the lowest quantity consistent with requirements

b The storage of articles in standard stock bins in which they are arranged alphabetically according to symbol

c The control of all materials withdrawn from the store or added to it by means of Issues and Credits; and the recording of every transaction on the balance-of-stores cards and the bin tags.

RESULTS ACCOMPLISHED IN THE BOX SHOP

88 The Eastern Manufacturing Company manufactures in an auxiliary department all of the packing cases in which paper is

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shipped. A large increase in business necessitated a greater number of cases than the Box Shop was able to produce under existing methods. In addition to those requirements, the company was desirous of making packing cases for its mill at Lincoln, Maine, instead of purchasing them from outside parties, a practice which had hitherto been followed. Before enlarging the shop or purchasing new and improved machinery, a study of this department was made and new methods introduced which enabled it to supply the increased requirements without the addition of more machinery or men.

89 The Box Shop is equipped with woodworking machinery on which the lumber for cases is planed, cut off, edged, matched, trimmed and resawed. A nailing machine is used to nail cleats on to the heads of the cases. The cases, after the sides, tops, bottoms and heads are made, are nailed together or "assembled" by hand.

90 As a result of the new methods of handling the work the daily output per operative of cases of the same materials was practically doubled. At the same time the earnings of the men were increased nearly 50 per cent.

91 This increase in output was secured through:

a A routing system by means of which orders were controlled and moved from operation to operation

b A new method of filling orders by assembling from a stock of shooks instead of making all parts for each order and assembling as the orders were run through

c Rates set on various operations from time studies made on each.

92 *Prevention of Lost Time.* A study of Box Shop conditions of existing methods disclosed the fact that each machine was equipped with an operator irrespective of the length of time his particular job took with reference to other jobs. When not actually running a machine, for lack of work, the operator "made himself generally useful around the shop" — in other words, did not do anything.

93 Time studies were made and the relative times of the operations ascertained. The organization, it should be stated here, was somewhat handicapped by the fact that no more than a certain output could be used in a given day and that the capacity of some of the machines was greatly in excess of the amount that could possibly be used. This explains a machine-time loss which in this particular case was unavoidable and legitimate.

94 The operations were so short and the orders so numerous that

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the different tasks were done on piece work. The Route Sheet for each order accompanied it through the shop, and as it passed through the different operations each worker detached a coupon bearing the name of the operation, the amount in the order, and the piece rate. This coupon was signed and turned in and from it his pay was figured.

95 It was found that much time could be saved in filling orders if the different parts were made ahead and placed in stock and these parts drawn from stock and assembled as the orders came through. There were thirty-three different standard sizes of cases and these constituted 90 per cent of the output. These were analyzed into the different sizes of tops, bottoms, sides, and heads required for each.

96 The past records of output were studied to determine the quantity of each size of case that would be required, and from these data a list of minimums and amounts to order for each part was calculated and a regular balance of stores kept on all of these parts. Orders are now made to replenish this stock when the minimum of any part has been reached; and orders for cases are filled by drawing the requisite number of each part from stock and simply assembling them.

STANDARDIZATION IN THE SULPHITE-PULP MILL

97 During the progress of the development in the paper mill, steps leading toward the standardization of methods in the sulphite-pulp mill were in progress, and soon, as a result of the satisfaction with the bonus system in the paper mill, there was a demand on the part of the men for the introduction of bonuses in the pulp making.

98 The results of the introduction of the standards and of the bonuses are illustrated by curves in the diagrams presented in the pages which follow. It will be seen by reference to Fig. 12 that the increase in production in the pulp mill from 1914 to 1916 was very large, while at the same time the materials used per ton of pulp were greatly reduced. This is notwithstanding the fact that previous to 1914 the quantities of materials used per ton of pulp were as low as in the average pulp mill.

99 Of special significance in the treatment of the pulp mill is the fact that the increase in output and the greater uniformity in quality were due directly to the establishment of standards of practice. Even when bonuses were introduced — and except in one or two in-

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stances these did not depend upon output — they were earned by following standard methods of procedure. This required a very high degree of skill and initiative on the part of the worker.

PROCESSES OF SULPHITE-PULP MANUFACTURE

100 To bring out more clearly the development in the pulp mill, we will describe very briefly the process of making the sulphite pulp.

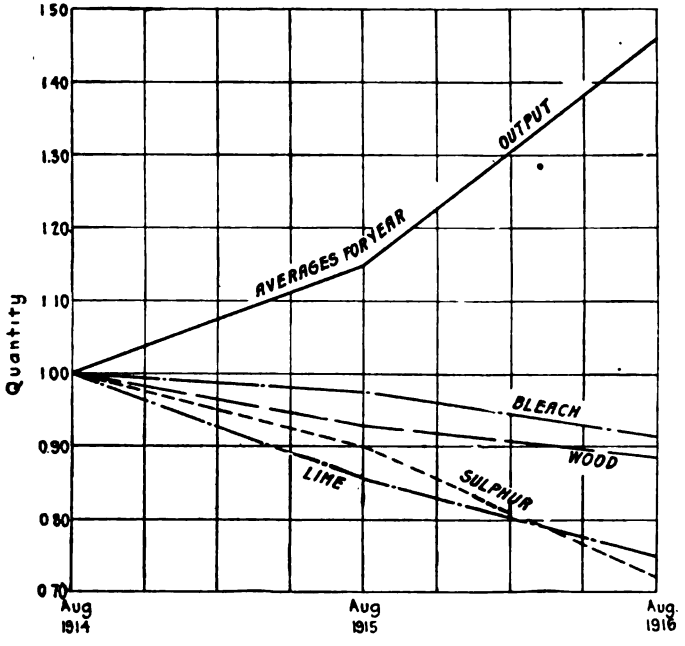

FIG. 12 RATIOS SHOWING DECREASE IN MATERIAL AND INCREASE IN OUTPUT FROM 1914 TO 1916

101 Logs ranging in diameter from 4 to 12 in., or even larger, and averaging about 6 in., come to the mill in 4-ft. lengths, and after cutting in two are barked, the bad knots are removed, and the pieces are run through a chipper which produces chips about ½ in. in length From the chipper they are raised to bins over the digesters. The steel digesters, about 14 ft. in diameter and 38 ft. high, lined with acid-proof lining, are filled with the chips, which are then covered with bi-sulphite-of-lime liquor produced by a combination of sulphur gas and

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slaked lime. After cooking for a period of 8 to 14 hours varying partly with the character of material, and partly with the judgment of the cook, the pulp is blown off into large tanks, being then of a consistency something like coarse, wet, short-fibered cotton. This pulp is washed in various ways, screened, bleached, and run either into wet sheets or rolls or in some cases pumped to the paper mill.

102 As usually made, the pulp is extremely variable, consequently no two cooks have exactly the same quality. The purpose of the standardization was to overcome this lack of uniformity and, as a consequence, to increase the production.

QUALITY OF WOOD

103 Studies were made of the characteristics of different kinds of wood, such as slabs, green wood, dry wood, peeled versus barked, and so on, to determine the relative economy and the quality of the pulp turned out. It was found through this investigation that sometimes the cheapest wood was the most expensive in terms of per ton of pulp.

STANDARDIZATION

104 The standardization of the pulp-making process involved, as it usually does, certain changes in plant as well as in methods of management. No radical changes were made, however, during the periods indicated on the diagrams referred to, December 1914 to December 1916. Many improvements since that time have been in progress, with the idea of reducing costs, increasing uniformity, and improving quality.

105 The standardization of the processes was taken up and carried through by the newly appointed Superintendent, Mr. B. M. Petrie, who also coöperated very effectively in the introduction of the bonus plan. The problem here, as elsewhere in plants where the process is a continuous one and not like the machine shop — or even the finishing department of a paper mill — capable of division, is one of scientific investigation to determine, in the first place, the proper materials and methods to produce the desired results, and, in the second place, to put these into effect as standards.

BONUS INSTALLATION IN PULP MILL

106 As already stated, bonus work was not begun in the pulp mill until it had been quite thoroughly developed in the paper mill, and then really as a result of a demand on the part of the operatives for the benefits being derived by their fellow-workmen in the adjacent

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mill. Before starting a bonus installation, many of the processes had been brought to a high standard of excellence and were thus ready for further development. As a matter of fact, the introduction of scientific management into a continuous process like a pulp mill, or the Making Department of a paper mill, consists more in the development of standards than in any routing or job analysis, which are so essential in other types of plants.

107 The bonuses in the pulp mill are of special interest because they are usually independent of questions of output. They involve the study of each operation and the arranging of a reward for meeting the standard requirements in each individual case. In general, the process consists in finding just what is being done, making extended investigations to determine the standards that should be fixed, and then introducing a plan for maintaining these standards. Two things must be always borne in mind, and neglect of these is responsible for many a failure in piece work and bonus work: First, no bonuses should be paid except on conditions for which the operative is responsible; and, second, the operator must know the plan and assist in working it out.

108 To illustrate the first point: One of the authors, visiting a plant where certain superficial developments had been made, inquired as to the wages per hour that were being received on a certain class of work. He was told that the range was from 25 cents to 40 cents. Asking why this great fluctuation on so simple a class of work, he was informed that it was entirely due to the character of the material which came to the worker. Now this was absolutely unfair, and penalized a man for something for which he was in no way responsible.

109 In a pulp mill the first consideration of a bonus system suggests the basing of bonuses on final output and quality of pulp. This is unfair to nearly all the men in the plant, because only a very few men are responsible for the output, the rest having simply a routine work to do to take care of the material which passes through their machines. Instead, therefore, of the uniformity scheme, each operation was considered by itself, and a bonus fixed to satisfy the requirement of individual responsibility.

110 While the bonuses thus are applicable only to these individual pulp-mill operations, they illustrate by their diversity the general principles for bonus payment in many manufacturing departments operating under a continuous process. Very briefly the bonuses adopted in a pulp mill will be discussed.

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111 *Bonuses in Wood Room.* The preparation and cutting up of the wood is a manufacturing proposition, but nearly all the outputs are limited by the requirements of the digester. Only where the output is dependent on the men themselves, as in barking, is the remuneration based on the quantity only. Even here, in fact, the amount of bonus is affected by the quality of the work done.

112 The bonuses of the men who handle the sticks to the wood room are based on uniformity of supply as recorded by a clock and in getting in the required quantity of wood on time. The bonuses of the men inspecting the logs on the carriers, and throwing out the poor ones, are reduced by the number of poor logs which they leave in and which the chipper men have to throw out. To balance this and also to prevent any collusion, the chipper men in turn are paid a bonus on every poor stick they throw out. Inspection of the work here as well as at other places further regulates the quality. As a matter of fact, in some of the work, such as that of the floor men and the men at the chip screens, a regular bonus is paid, provided the inspector, who makes his rounds at intervals, reports the work done as satisfactory.

113 *Acid-Making Bonus.* An acid maker is paid a bonus for keeping the strength of free acid within certain limits for specified temperatures; another bonus for maintaining the required strength for SO_2 gas, as shown by an automatic recorder; and still another for firing the sulphur furnaces within two minutes of the specified time.

114 The men who slake the lime are paid a bonus for keeping the strength of the slaked lime to the specified Baumé tests, and maintaining uniformity in the temperature of the lime water.

115 *Digester Bonuses.* The most important operation in pulp making is the cooking of the chips. The output of the digesters governs the production of the plant. Yet even here the bonuses were not based directly on the quantity produced. A somewhat more detailed description of the method of providing this bonus may be of interest.

116 By the old-fashioned method of cooking, and the method followed today by the majority of sulphite-pulp mills, the manner of cooking is put up entirely to the cook with certain directions and without sufficient apparatus to enable him to know what is going on in the digester. In the Bangor mill the first step was to provide, not simply pressure gages, but recording thermometers showing by curves at all times the temperature in the digester. By a careful study of

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the effect of different materials and conditions, a standard temperature curve was decided upon, and also a standard curve of pressure. This was done by the superintendent with the advice and assistance of the cooks. The temperature chart for each cooking is examined by the inspector in the office to determine how much it varies from the standard chart. Beginning two and a half hours after the cook is started, the deviation from the standard is noted by inspection at intervals throughout the remainder of the cook. If the curve is maintained within 3 deg. of the standard limits, the cook is paid a bonus of 3 cents per hour; if maintained within 4 deg. of the standard, he receives 2 cents an hour; within 5 deg., 1 cent per hour; while if it runs more than this he receives no bonus at all on this division of his work. A second bonus is paid for getting the pressure up to the required point at the designated time; a third bonus is paid for blowing off the cook at the proper color. The cooking liquor grows darker as the cook proceeds, and the exact time to blow off is governed by the color of the liquor, which can be drawn off through a cock. If the sample of liquor taken at time of blow-off is of the proper color, the cook receives a certain bonus; if the next color to it, a smaller bonus; if of the third color, a still smaller bonus. The total of the three bonuses constitutes his total bonus for the day. In practice the plan works out very simply and requires very little labor because the number of cooks per day are comparatively few.

117 One feature of the type of bonus which is of special interest is the graded amount. This plan is frequently followed by the authors, especially in cases where an exact standard is almost impossible to obtain or, on the other hand (and this does not apply to the pulp mill), where the physical characteristics of the operative, such as lack of muscular development or of experience, prevent his attaining the highest standard.

118 *Reduction in Cooking Time through Standardization.* Fig. 13 shows results of the standardization on the time of cooking. It will be seen by reference to the two curves that before introducing standards in the digester house, the length of cook varied anywhere from 8½ to 12 hours. After standardization, with all other conditions substantially the same, the variation, as shown by the full line, ranges from 10.4 to 11.3 as extremes. As a result of the great uniformity in the product produced, which eliminated entirely the poor cooks, it was found possible to reduce very materially the time of cooking below this latter curve. This reduction in time is one of the chief factors in the large increase in output shown in Fig. 12.

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FIG. 13 UNIFORMITY IN COOKING TIME THROUGH STANDARDIZATION

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119 *Wet-Room and Bleaching Bonuses.* The operations in the wet room consist in separating the fiber and washing and screening it. The bonuses for the different men were fixed in accordance with the individual conditions of the work, as in processes already described. In a number of the wet-room operations it was discovered after investigations involving extensive series of tests that the chief requisite for securing a pulp of the proper quality was the maintaining of a certain consistency or density, that is, having a uniform percentage of water mixed with the pulp. Consequently, a number of bonuses were fixed on density. In connection with the bleaching, for example, one of the bonuses was paid for maintaining the percentage of water within the defined limits. The effect of this on the product is shown in Fig. 14. The upper curve shows the large variation in density before the installation of the bonus, and the lower curve the greater uniformity obtained because the men were using greater ingenuity and care in manipulating their valves and were receiving a bonus for keeping within definite limits. Other features of the bonus on bleaching included maintenance of required temperatures, through manipulation of the valves, and more exact standardizing of the color.

DRY MACHINE

120 The final operation for the pulp which was to be sold consists in running it through the wet machine and over the dryers. To obtain uniformity of output and also a product uniform in quality, it is necessary to keep the sheet of a definite thickness and with a definite percentage of moisture. Consequently, limits were set for the percentage of moisture and also for the thickness of the sheet determined by recording tests of the regular samples, and bonuses were paid for keeping within the required limits.

INTRODUCING SCIENTIFIC METHODS INTO A NEWLY ACQUIRED PAPER MILL

121 The Eastern Manufacturing Company acquired in 1916 a one-machine paper mill located at Lincoln, Maine, some fifty miles north of Bangor, and it was decided to take the data acquired at Bangor and apply them directly to the new mill. The control of the manufacturing was placed in the Planning Department in Bangor, the two production men there handling both mills.

122 The systems of handling the production and the bonuses were installed by the company's production engineer, who had been

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trained at Bangor. He took with him the standards used at the old mill and was able to complete his work at the new mill within two months.

123 *Results at the Lincoln Mill.* The improved control produced through bonus work has been one of the most important results. In one or two cases where lack of certain unit times, not yet obtained, necessitated putting the operatives on day work, a telephone call comes from the Production Man asking if this job can't be put on bonus at once, "for if we don't we will get back to the old congested way."

124 The results have been as follows:

1 Congestion in the Finishing and Shipping Rooms has been eliminated
2 Shipment of orders is on a better schedule of time
3 Better conditions have resulted from more orderly arrangement or the storage of paper both while being finished and shipped
4 Production has increased
5 Wages have increased and a feeling of satisfaction has been produced among the employees.

PERSONNEL

125 Scientific Management is essentially a system of development — development of methods and development of the individual. Any attempt to emphasize the former and minimize the latter would result in failure. The development of the individual may be considered in two aspects — the material and the personal.

126 By material development is meant the training of the man or woman to become a more efficient and skilled worker, and so be able to demand and receive a high wage.

127 By the personal development is meant the growth of the individual himself, a growth which gives him a broadening point of view and permits him to see and appreciate the values of morality and decency, truth and sincerity, health and right living, self-respect and self-expression.

128 The material and the personal development are, to a great extent, interdependent. Scientific management considers them as essentially one. Older types of management have overlooked entirely the personal element or have viewed it in the wrong light.

129 *Advancement.* Not the least of these benefits to the em-

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ployees through scientific management is the greater opportunity for promotion. The quality of work done by each man or woman is recorded in the regular routine so that ability can be recognized. There is also a greater opportunity for adjustment and change from one class of work to another. Many of the clerks in the planning department, for example, came directly from the mill and were selected because of the intelligence and initiative shown in their regular work.

130 *Service Department.* So much importance has been attached to this feature of scientific management at the plant of the Eastern Manufacturing Company, that a department known as the Service Department — under the direction of a trained social worker — has been organized and deals directly with all matters pertaining to the personal development of the employees.

131 The functions of this department are as follows:

a To employ all help and to keep a set of employees' record cards

b To maintain a library for the free circulation of books

c To maintain a dispensary for the treatment and care of the sick or injured

d To operate a cafeteria at which wholesome food may be served to the employees at cost

e To inspect the factory and see that it is maintained at high standards as regards cleanliness, ventilation, sanitation, and safety

f To hear all complaints of employees regarding wages, treatment, or conditions; to investigate every complaint and when necessary see that matters are adjusted so that justice is always done

g To hear all complaints of foremen and department heads regarding employees; to investigate these thoroughly and to concur to any discipline or discharge that may be administered

h To coöperate with the employees in furthering any suggestions they may offer in regard to activities of a recreative or social nature

i To coöperate with all outside interests, municipal or private, that may have for their object the betterment of conditions in the community.

132 *Principles Involved.* It is not necessary to enlarge upon the

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foregoing except to emphasize very emphatically one point, namely, that the department, as its name indicates, is a department of service in the broadest sense of the word. It is conducted on democratic lines. Its activities are the expression of the workers themselves and not the policies of the management thrust upon them. There is nothing about it that savors of paternalism or of charity. It is strictly a business proposition, guided by the principle of scientific management that maintains that the development of the individual in every possible way is one of the requisites to an increase of pro-

FIG. 15 CAFETERIA

duction — production not only of materials, but of all the worthwhile things of life.

133 To provide suitable quarters for the Service Department a new floor has been built on the finishing building. This contains a men's rest and smoking room; a women's rest room, with the offices and nurses' quarters at the side, and the cafeteria which is shown in Fig. 15.

134 *Results Accomplished by Service Department.* The results that are being accomplished through this phase of scientific management are:

a The development of a set of independent, self-respecting men and women who are skilled in their work

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b The establishment of a better understanding between the management and the employee. Without this feature of management the employer generally does not even know who his employees are. With it, he is constantly having the affairs of individuals forced upon his attention until he must recognize his ever-growing responsibilities to his workers. And through the same medium, the employee is led to some insight into management and an understanding of methods that he otherwise could not comprehend.

135 As usual in any really permanent piece of management development for which engineering advice is obtained, the results cannot be attributed to any one man or group of men, but have been produced by the coöperation of all concerned. For a considerable period the work was carried on under the direct supervision of the consulting engineers and their resident engineer, but the entire responsibility was gradually taken over by the mill organization. Success in this plant in particular was made possible in a large measure by the progressive ideas and friendly coöperation of the managers.

136 The best evidence of the spirit of research and progress developed by scientific management is the fact that the mill organization is continuing to make rapid strides in the line of discovery and improvements, calling to its aid whatever science is necessary for the solving of each problem and for the elimination of obstacles.

DISCUSSION

W. H. CARRIER said that it seemed rather remarkable that time study as related to efficiency as a whole from a scientific and from a manufacturing standpoint had progressed so little in the paper-making art in the last number of years as compared with other arts in this country, particularly with reference to the work in the machine room. He was not a paper-mill man, but had been connected with problems in paper mills where the lack of manufacturing efficiency in the art of paper production had been most striking.

It had been determined by several different observers, for instance, that in the process of the machine room in the drying of the paper from 30 to 50 per cent of the possible strength of the paper was lost; and that the cost of producing paper of a standard

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as high as writing paper was nearly double what it might be if improved methods were introduced and studies made.

Even at the present date it had been shown by actual tests to be possible either to increase the strength of the paper or decrease the cost of a given standard from 5 to 15 per cent by the use of improved methods, and at the same time to increase the output 10 to 20 per cent by the use of improvements in drying, particularly the application of air and the proper handling of the rolls.

Comparatively few machine rooms were being provided with improved machinery, although their number was increasing. But there should be a thorough study made of the possibilities which would result, he was certain, in a practical revolution of the process of paper making by machinery.

CALVIN W. RICE asked what proportion of the value of the product of a paper mill the cost of counting the sheets represented. He asked whether the product had now been developed to such a uniformity that the number of sheets could be arrived at by weighing them, and if not, whether other processes had been found which would avoid the expense of counting.

HARRINGTON EMERSON said that some seven years ago he was engaged to standardize the work in a paper mill very similar in size to the one described in the paper. His assistants standardized operations in a number of departments. There were at least 3500 different varieties of paper. A great deal of work done there would have been very useful to Mr. Thompson at the beginning of his studies, and with it as a basis he would undoubtedly have extended the studies already made.

Mr. Emerson mentioned this because he felt that he also was often duplicating work already more thoroughly done by Mr. Thompson and others, and he regretted that there was no available clearing house of experiences.

As an evidence of the thoroughness with which some of the work was done, he would say that the plant in question was the only place in the world as far as he knew in which labor costs were so immediately and accurately distributed that in nine months they were not one mill out on the work of 600 or 700 men, and the distribution of labor costs to orders was complete at 10 a.m. of the day following. The work was performed by three girls, one of whom was a substitute.

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FRANK B. GILBRETH said that he wished to take great exception to Mr. Thompson's admirable paper, in that he followed out the procedure of his predecessors in giving the impression that there were such things as elementary units in stop-watch time study, and that the data obtained from such study were accurate, transferable and of permanent value.

He wanted to call attention to the fact that the Society could not go very far in utilizing data unless they were in such form that they were usable by all the members. Stop-watch time study was inaccurate, through the fact that the variable of the human element was involved in pressing and reading the stop watch, and in writing the record. It was not transferable, in that it did not provide for recording the surrounding conditions under which the observed activity took place. For these two reasons, among many others, it lacked permanent value.

It was possible to obtain accurate records of activity that included not only the time taken by the activity but also the time of really elementary units of which it was composed, through methods that were inexpensive, available and adequate. Through the use of the micromotion method and the cyclegraph method, which he illustrated by lantern slides, it was possible to obtain data that were so complete and so accurate that they were usable at any time by any person. From these data might be obtained charts that would enable one to transfer the facts obtained not only from one activity to another but from one type of worker to another who had an entirely different mental, physical, or material equipment.

The special importance of these facts at this time was their relation to waste elimination. If we were to do our part in the savings that were today so necessary, we must begin to collect our data in a more economical fashion and put them into such shape that they might be universally useful in the shortest amount of time possible. He would therefore urge such men as Mr. Thompson, who had both the natural ability and the training that lead to expertness in observing and recording data, to discard inaccurate and unscientific devices and to insure that the results of investigations were both immediately and permanently usable.

SANFORD E. THOMPSON replied to Mr. Rice that sheets still were counted in many kinds of paper. The cost of counting, however, using the rubber finger tip and counting by fives, was small, considerably less than one cent per ream. They had found that for

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the thicker grades it was possible to count by measurement of the thickness of the pile.

He considered that Mr. Carrier was too low in his percentages of possible cost reduction. There was a chance for an appreciable increase in production and improvement in quality by radical changes in machinery, not only in the paper machine, but also in the beating engines, and these problems were now being studied in the mills referred to in the paper. All paper mills are still using the Hollander beating engine, which was invented not less than fifty years ago.

Mr. Gilbreth was correct in his statement that time study was capable of further standardization, and that we had gone only a very short way in the developing of standard methods of taking time and in getting these methods so that the results of different operators would be comparable. He was not quite ready to admit, however, that Mr. Gilbreth's methods would revolutionize the taking of times, although he felt that moving pictures could be of great value in many cases.

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No. 1588

DISK-WHEEL STRESS DETERMINATION

By S. H. Weaver,[1] Schenectady, N. Y.
Non-Member

This paper describes and applies a simplified method for determining the centrifugal stresses in a disk wheel of given irregular shapes of section. Stodola's disk theory is assumed, together with his formula for disks of hyperbolic-section profile. The formulæ are then transformed so as to give the tangential stresses at the inner and outer radii in terms of the radial stresses, ratio of radii, and shape constant of disk section.

For a given disk with a single hyperbolic outline the tangential stresses are expressed in terms of the radial stresses or loads; and if the latter are known, the stresses are determinate. In case the disk-section outline would require to be fitted by two hyperbolas meeting at the same thickness of disk, the wheel section can be divided at the meeting point of the curves into two imaginary rings. The rings at the meeting point, by the continuity of material and same thickness, are held together by a radial stress common to both and have the same elongation and tangential stress. One can then write the tangential stress of the one ring equal to the tangential stress of the other at their common radii, giving one equation with the one unknown quantity, the radial stress common to both, and all stresses are determinate. Thus any irregular-shaped disk can be fitted within hyperbolas, divided into n imaginary rings, and $(n - 1)$ equations written for the common meeting points of the curves with $(n - 1)$ unknown radial stresses, and the stress problem is solvable.

The six coefficients whose values are given in Equation [4] as functions of the ratio of radii and hyperbolic outline of disk section, are laborious to calculate but should be used for accurate results. For commercial work approximate equations [6] are given which cover the practical disk proportions, and within the limits shown have a range of error of less than one per cent.

As a further labor-saving device when a number of disks are to be estimated, the approximate equations can be placed in an alignment-chart form. An appendix gives the range and proportion of the five charts required which experience has shown to be the most useful. The number and size of these charts for accurate reading do not permit of reproduction.

A practical example is given showing the actual application to the usual disk wheel.

[1] General Electric Company.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of The American Society of Mechanical Engineers.

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IN high-speed machine parts a disk construction of the rotating element is often necessary, because a disk shape has a smaller maximum stress in the material used than any other construction; and to reduce the maximum stress still further the section of the disk is given an irregular shape, which, however, makes the stress determination more difficult. The mathematical determination of the three stresses, radial, tangential, and axial, acting at a given point in the disk section, is impractical. But if there is no sudden change in the axial thickness of the disk, as at a hub, the axial stress is of negligible value, and the mathematical side is greatly simplified by considering only the radial and tangential stresses. This method is treated fully in Stodola's Die Dampfturbinen and Stodola's Steam Turbine, translated by Dr. L. C. Loewenstein, Mem.Am.Soc.M.E.,

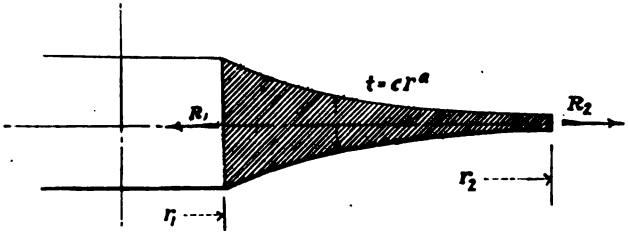

FIG. 1 DISK PROFILE, GIVING STRESS DATA

but the resulting formula is left in such a form that it is difficult to apply, even by those well acquainted with the theory and the mathematics.

2 In this paper is described a method developed for, and used by, the General Electric Company, which has resulted in reducing the time required for a stress computation of an irregular-shaped turbine disk wheel to about one-tenth of that required for previous computations.

3 While the profile of the radial sections of disk wheels is usually made up of straight lines and arcs of circles, the equations of such lines present mathematical difficulties in the solution. The outline of the disk section can be closely approximated by one or more hyperbolas with the equation $t = cr^a$, where t is the thickness at the radius r, c is a dimension constant, and a is a shape constant for the profile of the section; a has a negative value when the thickness decreases with a larger radius, a zero value for a constant or uniform thickness, and a positive value when the thickness increases with a

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larger radius. For a given disk profile (see Fig. 1) the value of a may be found from

$$a = \frac{\log (t_2/t_1)}{\log (r_2/r_1)} \quad \text{or} \quad = -\frac{\log (t_1/t_2)}{\log (r_2/r_1)} \qquad \text{[1]}$$

the formula being chosen which gives one or more for the ratio of thickness numerically.

4 The equations of the tangential and radial stresses as given in the above reference are as follows:

$$m_1 = -\frac{a}{2} - \sqrt{\frac{a^2}{4} - Va + 1}, \quad m_2 = -\frac{a}{2} + \sqrt{\frac{a^2}{4} - Va + 1}$$

$$p = -\frac{(1 - V^2)\, uw^2}{E_1 [8 + (3 + V)\, a]}$$

$$R = \frac{E_1}{1 - V^2}\left[(3 + V)\, pr^2 + (m_1 + V)\, b_1 r^{m_1 - 1} + (m_2 + V)\, b_{11} r^{m_2 - 1}\right]$$

$$T = \frac{E_1}{1 - V^2}\left[(1 + 3\,V) pr^2 + (1 + m_1 V) b_1 r^{m_1 - 1} + (1 + m_2 V)\, b_{11} r^{m_2 - 1}\right]$$

where m_1, m_2 and p are algebraic quantities

a = shape constant of profile of disk section
u = mass of disk material per unit of volume
w = angular velocity of rotation
V = Poisson's ratio of deformation = 0.3 for steel
E_1 = Young's modulus of elasticity
R = radial stress at radius r
T = tangential stress at radius r
r = any radius in disk section
b_1 and b_{11} = boundary-condition constants.

5 To transform these equations it will be necessary to know two stresses so as to determine the values of the condition constants b_1 and b_{11}. Assume a known radial stress R_1 at radius r_1 and R_2 at radius r_2, then write from the above equations

$$R_1 = \frac{E_1}{1 - V^2}[(3 + V)\, pr_1^2 + (m_1 + V)\, b_1 r_1^{m_1 - 1} + (m_2 + V)\, b_{11} r_1^{m_2 - 1}]$$

$$R_2 = \frac{E_1}{1 - V^2}[(3 + V)\, pr_2^2 + (m_1 + V)\, b_1 r_2^{m_1 - 1} + (m_2 + V)\, b_{11} r_2^{m_2 - 1}]$$

Solving for b_1 and b_{11} gives, writing $K = \frac{r_1}{r_2}$,

$$b_1 = -\frac{1 - V^2}{E_1}\frac{[R_1 - K^{m_2 - 1} R_2] + (3 + V)\, pr_2^2 [K^{m_2 - 1} - K^2]}{(m_1 + V)\,(K^{m_2 - 1} - K^{m_1 - 1})\, r_2^{m_1 - 1}}$$

$$b_{11} = +\frac{1 - V^2}{E_1}\frac{[R_1 - K^{m_1 - 1} R_2] + (3 + V)\, pr_2^2 [K^{m_1 - 1} - K^2]}{(m_2 + V)\,(K^{m_2 - 1} - K^{m_1 - 1})\, r_2^{m_2 - 1}}$$

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Placing in the original equation for tangential stress the value of T_1 at r_1 and T_2 at r_2 with $K = r_1/r_2$, gives

$$T_1 = \frac{E_1}{1 - V^2}[(1 + 3V)\, pK^2 r_2^2 + (1 + m_1 V)\, b_1 (Kr_2)^{m_1 - 1} + (1 + m_2 V)\, b_{11} (Kr_2)^{m_2 - 1}]$$

$$T_2 = \frac{E_1}{1 - V^2}[(1 + 3V)\, pr_2^2 + (1 + m_1 V)\, b_1 r_2^{m_1 - 1} + (1 + m_2 V)\, b_{11} r_2^{m_2 - 1}]$$

6 Substituting in these equations the values of b_1 and b_{11} as derived above, and remembering that

$$\frac{1 + m_1 V}{m_1 + V} = -m_2, \quad \frac{1 + m_2 V}{m_2 + V} = -m_1, \quad m_1 + m_2 = -a,$$

gives $T_1 = Ar_2^2 - BR_1 + CR_2, \quad T_2 = Dr_2^2 - ER_1 + FR_2, \ldots\ldots$ [2]

where $B = \dfrac{m_1 K^{m_2 - 1} - m_2 K^{m_1 - 1}}{K^{m_2 - 1} - K^{m_1 - 1}}, \quad E = \dfrac{m_1 - m_2}{K^{m_2 - 1} - K^{m_1 - 1}},$

$$C = \frac{E}{K^{a+2}}, \quad F = B + a. \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3]$$

$$A = -\frac{uw^2}{8 + (3 + V)\, a}[(1 + 3V)\, K^2 + (3 + V)\, (K^2 B - C)]$$

$$D = -\frac{uw^2}{8 + (3 + V)\, a}[(1 + 3V) + (3 + V)\, (K^2 E - F)]$$

The formulæ for A and D can be further simplified by substituting numerical values for constant conditions in practice.

7 Disk wheels are usually made of cast steel or steel forging, the weight of material varying from 0.28 to 0.283 lb. per cu. in. Take the average value 0.2815, because it will result in an even numeral in the reduction; gravity is 32.16 × 12 in. per sec. per sec.; Poisson's ratio of deformation $V = 0.3$. The stresses due to the external centrifugal load and the weight of disk itself vary as the square of the speed. One can then take a constant 1000 r.p.m. for all disks, and after finding stress values, reduce to any desired speed by multiplying by the square of the speed ratio.

8 With these values

$$\frac{uw^2}{8 + (3 + V)\, a} = \frac{\dfrac{0.2815}{32.16 \times 12}\left(\dfrac{2\pi \times 1000}{60}\right)^2}{8 + (3 + 0.3)\, a} = \frac{1}{1 + 0.4125\, a}$$

$$A = \frac{3.3\,(C - K^2 B) - 1.9\, K^2}{1 + 0.4125\, a}, \quad D = \frac{3.3\,(F - K^2 E) - 1.9}{1 + 0.4125\, a}$$

Collect the formulæ required for a solution of the stresses (see Fig. 1).

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$$K = \frac{r_1}{r_2}, \quad a = \frac{\log (t_2/t_1)}{\log (1/k)} \quad \text{or} \quad = -\frac{\log (t_1/t_2)}{\log (1/k)},$$

$$m_1 = -\frac{a}{2} - \sqrt{\frac{a^2}{4} - 0.3\,a + 1}, \quad m_2 = -\frac{a}{2} + \sqrt{\frac{a^2}{4} - 0.3\,a + 1}$$

$$B = \frac{m_1 K^{m_2-1} - m_2 K^{m_1-1}}{K^{m_2-1} - K^{m_1-1}}, \quad E = \frac{m_1 - m_2}{K^{m_2-1} - K^{m_1-1}}, \quad C = \frac{E}{K^{a+2}}$$

$$F = B + a$$

$$A = \frac{3.3\,(C - K^2 B) - 1.9\,K^2}{1 + 0.4125\,a}, \quad D = \frac{3.3\,(F - K^2 E) - 1.9}{1 + 0.4125\,a} \qquad \text{..[4]}$$

The tangential stresses at r_1 and r_2 are

$$T_1 = Ar_2^2 - BR_1 + CR_2 \text{.....[5a]}$$

$$T_2 = Dr_2^2 - ER_1 + FR_2 \text{.....[5b]}$$

9 These formulæ are in a form more easily applied than the original ones. The factors A, B, C, D, E and F are functions only of the shape constant a and the ratio of radii K; and when they are computed in a given disk for particular values of a and K, they may be preserved in tabulated form for future problems involving the same a and K and may be used even if the actual dimensions and speed of the wheel are entirely different.

10 As the determination of the values of the functions consumes the greater part of the time in a stress calculation, the next attempt was to place the tabulated values of the functions in a curve form with the function and a and K as variables. When plotted on rectangular coördinates, the curves covered so much space and some of the functions gave curves crossing each other in such a maze that it was impossible to read the values. For the form of an alignment chart the functions are so complicated that an accurately constructed chart would involve cumulative readings, introducing too large an error in the final values read. The conditions were finally met by using simple alignment charts based on approximate equations with known, negligible errors.

11 The approximate equations were found by a combination of mathematical and cut-and-try methods and apply to the disks of practical proportions. The ratio of thicknesses is limited to a value not greater than 5. For values of a between 0 and -5 and K between 0.1 and 0.8 (except C where the K range is 0.4 to 0.8), the total range of error from the plus to the minus value is about 0.7 of one per cent. For the large plus values of a between 0 and $+40$ and K between 0.8 and 0.97, the total range of error is about 0.6 of one per cent.

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12 These approximate equations are, using common logarithms:

$$\left.\begin{aligned}
B &= \frac{\log\frac{1}{K}}{5.43}(a^2 - 1.2\,a) - \frac{a}{2} + \left(\frac{2}{1-K^2} - 1\right), \quad F = B + a \\
E &= \frac{\log\frac{1}{K}}{10}(a^2 + 10\,a) - \frac{a}{2} + \left(\frac{2}{1-K^2} - 2\right) \quad \left[\begin{matrix}0.8\\0.1\end{matrix}K\left[\begin{matrix}-5\\0\end{matrix}a\right.\right. \\
&= \frac{\log\frac{1}{K}}{7}(a^2 + 10\,a) - \frac{a}{2} + \left(\frac{2}{1-K^2} - 2\right) \quad \left[\begin{matrix}0.97\\0.8\end{matrix}K\left[\begin{matrix}40\\0\end{matrix}a\right.\right. \\
C &= \frac{\log\frac{1}{K}}{3.33}(a^2 + 4.8a) + \frac{a}{2} + \frac{2}{1-K^2} \quad \left[\begin{matrix}0.8\\0.4\end{matrix}K\left[\begin{matrix}-5\\0\end{matrix}a\right.\right. \\
&= \frac{\log\frac{1}{K}}{4.65}(a^2 + 6\,a) + \frac{a}{2} + \frac{2}{1-K^2} \quad \left[\begin{matrix}0.97\\0.8\end{matrix}K\left[\begin{matrix}40\\0\end{matrix}a\right.\right. \\
A &= 3.1\,(1-K)^{2.00}\,a + (6.6 + 1.4\,K^2) \\
D &= 1.25\,(1-K)^{1.75}\,a + (6.6\,K^2 + 1.4)
\end{aligned}\right\} \ldots [6]$$

On charts made from the above equations one can read three numerals from the scales, which is close enough for commercial stress work.

13 Wheels usually have parts of uniform or constant thickness, and the values of the functions are then so simple that they can be calculated accurately as quickly as reading the values from the charts. For uniform thickness the functions reduce to

$$\left.\begin{aligned}
&a = 0, \quad K = \frac{r_1}{r_2}, \quad C = \frac{2}{1-K^2}, \quad B = F = C - 1, \quad E = C - 2 \\
&A = 6.6 + 1.4\,K^2, \quad D = 6.6\,K^2 + 1.4
\end{aligned}\right\} \ldots [7]$$

with A and D for 1000 r.p.m. and disk material of 0.2815 lb. per cu. in.

EXAMPLE

14 The application of the formulæ and principle involved can be shown in connection with an example. Fig. 2 shows the half-section of a disk wheel designed to run at 3600 r.p.m. The profile of the disk must be represented by a number of connecting hyperbolas whose a value can be found from Equation [4]. The disk section is divided into sub-sections or rings numbered 1, 2, 3, 4 and 5, each sub-section having a value of a, and the same thickness where they join the adjacent section. Rings 1 and 5 are of uniform thickness, hence

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a is zero. Ring 4, the thickness of which increases very rapidly with the radius, has a large positive value for a. For the part marked rings 2 and 3, two sections are used because the profile is better represented by larger values of K, and since the thickness decreases as the radius increases, both values of a are negative.

15 Of the different radial stresses two must be known. The radial stress at the bore may be taken as zero, for the shrink fit with which the wheel is placed on the shaft may be supposed to be almost neutralized at normal speed by the centrifugal expansion at the bore, and at some overspeed the radial stress is zero. The outer radial stress of the bucket load equals the centrifugal force of the buckets, covers, etc., at 1000 r.p.m. (14.2 × weight in lb. × diameter in in.)

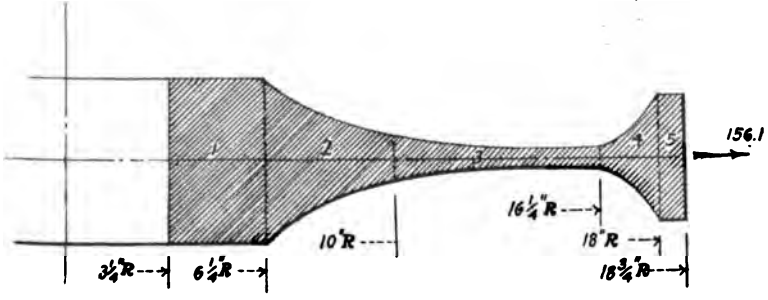

FIG. 2 HALF-SECTION OF DISK WHEEL DESIGNED TO RUN 3600 R.P.M.

divided by the outer cylindrical area of the rim. In the example this radial pull per sq. in. of surface at $r = 18\frac{3}{4}$ in. is 156.1 lb. per sq. in. at 1000 r.p.m.

16 Let the unknown radial stress at the lines dividing the imaginary rings be e between rings 1 and 2, f between rings 2 and 3, g between rings 3 and 4, and h between rings 4 and 5. Collect the data in tabular form (Table 1). For the constants A to F calculate for accurate work from Equations [4] and [7]; for approximate results calculate from Equations [6] and [7], or read from alignment charts values of Equation [6] when placed in chart form.

17 From construction there is only one thickness at any given radius, therefore only one set of stress values at any particular radius. Thus at the line dividing the imaginary rings 1 and 2 there can be only one radial stress e and one tangential stress, so that one can write the outer tangential stress of ring 1 by Equation [5b] equal to the inner tangential stress of ring 2 by Equation [5a]. In the same way at the

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line separating rings 2 and 3, the outer tangential stress of ring 2 equals the inner tangential stress of ring 3. Write an equality of the tangential stress for each division line between imaginary rings and then solve for the unknown radial stresses (e, f, g and h).

18 The equalities of the tangential stresses are:

at $r = 6.25$,

$3.18 \times (6.25)^2 - 7.4 \times 0 + 1.74\,e = 5.99 \times (10)^2 - 4.17\,e + 1.49\,f$;

at $r = 10$,

$3.33 \times (10)^2 - 2.31\,e + 1.27\,f = 6.58 \times (16.25)^2 - 2.99\,f + 2.25\,g$;

at $r = 16.25$,

$3.59 \times (16.25)^2 - 1.62\,f + 1.69\,g = 8.09 \times (18)^2 - 4.03\,g + 21.33\,h$;

at $r = 18$,

$7.09 \times (18)^2 - 3.75\,g + 19.03\,h = 7.89 \times (18.75)^2 - 24.51\,h + 25.51 \times 156.1$.

TABLE 1 DATA FOR STRESSES AT LINES DIVIDING THE IMAGINARY RINGS IN FIG. 2

Ring Number	1	2	3	4	5
r_1	3.25	6.25	10.00	16.25	18.00
r_2	6.25	10.00	16.25	18.00	18.75
t_1	5.00	5.00	1.28	0.68	3.14
t_2	5.00	1.28	0.68	3.14	3.14
$K = r_1/r_2$	0.52	0.625	0.615	0.903	0.96
a	0.00	−2.9	−1.3	15.00	0.00
R_1	0.00	e	f	g	h
R_2	e	f	g	h	156.1
A	6.98	5.99	6.58	8.09	7.89
B	1.74	4.17	2.99	4.03	24.51
C	2.74	1.49	2.25	21.33	25.51
D	3.18	3.33	3.59	7.09	7.48
E	0.74	2.31	1.62	3.75	23.51
$F = B + a$	1.74	1.27	1.69	19.03	24.51

19 The solution of these equations gives

$$e = 433, \quad f = 1398, \quad g = 1578, \quad \text{and} \quad h = 238.$$

Substituting in either the right or left side of the above equations gives the tangential stress at the respective radii. The tangential stress at the bore is $6.98 \times (6.25)^2 - 1.74 \times 0 + 2.74 \times 433 = 1458$; at the outer rim $= 7.48 \times (18.75)^2 - 23.51 \times 238 + 24.51 \times 156.1 = 853$. The stresses at 1000 r.p.m. are

for r =	3.25	6.25	10	16.25	18	18.75
R =	0	433	1398	1578	238	156
T =	1458	877	1109	1345	915	853

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The stress at intermediate points in any ring can be computed from the above known values by the use of both Equations [5*a*] and [5*b*].

20 For 3600 r.p.m. all the stresses should be multiplied by $(3600/1000)^2 = 12.96$, giving

for						
r	= 3.25	6.25	10	16.25	18	18.75
R	= 0	5608	18115	20450	3189	2020
T	= 18900	11386	14368	17430	11858	11052

The radial elongation at any radius r is $\epsilon = (T - 0.3\,R)r/29{,}000{,}000$, where 29,000,000 is the modulus of elasticity of the disk material. The radial elongation at 3600 r.p.m. is then

for						
r	= 3.25	6.25	10	16.25	18	18.75
ϵ	= 0.00212	0.00208	0.00308	0.00633	0.00677	0.00676

21 The time required for an accurate solution, using the original Stodola formula, is about forty-five hours; the use of the approximate formula in alignment-chart form reduces the time to about five hours. As to the error in the approximation, a comparison has been made on seven disks in which one wheel had the maximum stress one per cent low; the remaining disks had too high a value of stress, the greatest error being three per cent.

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APPENDIX

ALIGNMENT CHARTS

22 While any one acquainted with alignment charts can place Equation [6] in chart form, experience has shown the methods that involve the least amount of work and the range of values required. Each function or letter is placed in two charts, one for the a range of 0 to -5, and the other for the a range of 0 to $+40$.

23 A chart. Title, "Ar_1^2 = tangential stress at r_1 at 1000 r.p.m. due to the weight of disk. When $a = 0$, $A = 6.6 + 1.4\,K^2$." The a scale is linear and ranges from 0 at the bottom to -5 at the top. The A scale is linear and ranges from 3 at the bottom to 7.5 at the top. K varies from 0 to 0.8. The support or middle scale with values of K is curved. Locate the points for $K = 0.8$, 0.7, 0.6, etc., by using two values of a, say 0 and -3, then draw a smooth curve through the points. The smaller divisions are located by using A values for $a = 0$. In the second A chart, the a scale is linear and ranges from 0 at the top to $+40$ at the bottom; the A scale is linear and ranges from 7.5 at the bottom to 8.5 at the top, while K varies from 0.8 to 1, the K points being located as in the first chart.

24 D chart. Title, "Dr_2^2 = tangential stress at r_2 at 1000 r.p.m. due to the weight of disk. When $a = 0$, $D = 6.6\,K^2 + 1.4$." The a scale is linear and ranges from 0 at bottom to -5 at the top. The D scale is linear and ranges from 1.5 at bottom to 5.5 at the top. K varies from 0 to 0.8. The D chart is constructed the same as the A chart. In the second D chart the a scale is linear and ranges from 0 at top to $+40$ at bottom. The D scale is linear and ranges from 5.5 at bottom to 8 at the top. K varies from 0.8 to 1.

25 B and F chart. Title, "$B = X - \frac{a}{2}$, $F = X + \frac{a}{2}$, BR_1 = tangential stress at r_1 due to the radial stress R_1. FR_2 = tangential stress at r_2 due to the radial stress R_2. When $a = 0$, $B = F = C - 1$." The equation is

$$B + \frac{a}{2} = F - \frac{a}{2} = X = \frac{\log \frac{1}{K}}{5.43}(a^2 - 1.2\,a) + \left(\frac{2}{1 - K^2} - 1\right).$$

In the first chart, a values are from 0 at top to -4 at bottom of scale, plotting distance from zero of $(a^2 - 1.2\,a)$ instead of a. The range is from 0 for $a = 0$ to 20.8 for $a = -4$. The range of the X scale is linear from 1 at the bottom to 5 at the top. K varies from 0 to 0.8 and is located as in the A curve. In the second chart, the a scale ranges from 0 at the top to $+40$ at bottom and is scaled by the values from $(a^2 - 1.2\,a)$. The range is from 0 for $a = 0$ to 1552 for $a = 40$. The X scale is linear and ranges from 5 at the bottom to 35 at the top. K varies from 0.8 to 0.97.

26 C chart. Title, "$C = y + \frac{a}{2}$. CR_2 = tangential stress at r_1 due to the radial stress R_2. When $a = 0$, $C = \frac{2}{1 - K^2}$." The equation is

$$C - \frac{a}{2} = y = \frac{\log \frac{1}{K}}{3.33}(a^2 + 4.8\,a) + \frac{2}{1 - K^2}.$$

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In the first chart a varies from 0 to -4.8, plotting distance of a on the scale from zero at the bottom from the value $(a^2 + 4.8\,a)$ to $a = -2.4$ at the top. Range of scale distance, 0 to 5.76; y scale is linear and ranges from 0 at bottom to 5.5 at the top. K varies from 0.4 to 0.8; the points are located as in the other curves. In the second chart a varies from 0 to $+40$, plotting scale distance of a from 0 at the top to $+40$ at the bottom from the values of $(a^2 + 6\,a)$. The equation is

$$C - \frac{a}{2} = y = \frac{\log \frac{1}{K}}{4.65}(a^2 + 6\,a) + \frac{2}{1 - K^2}.$$

The range of scale distance is 0 to 1840; y scale is linear and ranges from 0 at bottom to 30 at the top. K varies from 0.8 to 0.97.

27 E chart. Title, "$E = Z - \frac{a}{2}$. ER_1 = tangential stress at r_2 due to the radial stress R_1. When $a = 0$, $E = C - 2$." The equation for the first chart is

$$E + \frac{a}{2} = Z = \frac{\log \frac{1}{K}}{10}(a^2 + 10\,a) + \frac{2}{1 - K^2} - 2.$$

a varies from 0 at bottom to -5 at top, and scale distance is measured from 0 by the value of $(a^2 + 10\,a)$. The range of distance is 0 to 25. The Z scale is linear and ranges from 0 at the bottom to 3.6 at the top. K varies from 0.4 to 0.8, with the points for K located as in previous charts. The equation for the second chart is

$$E + \frac{a}{2} = Z = \frac{\log \frac{1}{K}}{7}(a^2 + 10\,a) + \frac{2}{1 - K^2} - 2$$

where a varies from 0 to $+40$, plotting the scale distance of a from 0 at the top by means of the values from $(a^2 + 10\,a)$. The range of distance is 0 to 2000. The Z scale is linear and ranges from 3.5 at the bottom to 30 at the top. K varies from 0.8 to 0.97, with the points for K located as in the other curves.

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No. 1589

A FOUNDATION FOR MACHINE-TOOL DESIGN AND CONSTRUCTION

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Member of the Society

The author emphasizes the fact that engineering development has been most rapid in those branches which have had the assistance of mathematics and science. For example, the development of the steam engine in its first stages was slow and hesitating; but when the fundamental facts of thermodynamics were understood its progress became more rapid. It thus became possible to imagine a 100-per-cent-efficient engine working on an ideal cycle, with which the operative engine could be compared.

Similarly, in respect to machine tools, questions are enumerated upon which information is needed in order to follow the line of recent development of the steam engine. These relate particularly to the functions and action of the cutting tool, the action of the cutting lubricant, etc.

Experiments already made by the author are outlined and suggested lines of experimentation are indicated.

THE rapidity of progress of the various branches of engineering may be said to be in proportion to the ease with which their principles can be reduced to mathematics. This was perhaps never so clearly shown as in the case of the development of alternating-current apparatus. It may almost be said that the branch of alternating-current engineering was, like Pallas Athene, born full-grown. Here was a case where the science, the mathematics of this branch, was at hand, waiting for somebody to apply it. As a result, alternating-current apparatus has known no period of experimentation, of stumbling, fumbling progress.

2 Compare this with the slow, hesitating development of the steam engine in its first stages. In that case nothing was known except that steam would exert pressure; but no knowledge existed of the properties of steam, of thermodynamics, nor of the mathematics of engineering materials. The moment that the fundamental facts of thermodynamics were understood, and were reduced to mathematics, the progress of the steam engine became more rapid.

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3 Many instances could be given to show that the opening statement of this paper is true; but the writer believes that the truth of the statement is so well recognized nowadays that further proof may be omitted. There are branches of engineering which are not capable of such rapid development, because their fundamentals are not so much based on science as on art. Though ceramics may be assisted by the engineer, it can never be a true branch of engineering, because it depends on art, on skill, and not on science. All that science can do for ceramics is to improve the facilities for applying the art of the workman, for expediting his processes, and for delivering the materials to the artists. The same, though to a lesser degree, may be said of the textile industry.

4 There are other branches of engineering which have not had the assistance of science up to the present time, but which might have that assistance if science could dig out the foundations on which these branches of engineering rest.

5 Machine-shop methods have, as a whole, developed so slowly and through so many centuries that we are apt to forget that these methods should, and actually do, rest on fundamental knowledge of materials to be worked, and tools to work with.

6 As it is, the knowledge we have is legendary; transmitted from father to son, or from teacher to pupil, by word of mouth. Now and then some article or book has been written describing the methods in use but without giving any fundamentals, and, as a consequence, is soon forgotten or replaced by some more up-to-date or more fashionable knowledge. Considering the fact that by far the greater part of mechanical-engineering work is done in workshops, and that by far the greater work done in these workshops has to do with the cutting of metals, it is really surprising that no positive knowledge exists on this subject. Millions of people have spent a large portion of their lives cutting metals; improvements in tools and methods have been made, and yet, at the present day, we cannot predict along what lines we may look for further progress. Here and there attempts have been made by individuals to reduce to a system the fragmentary knowledge that we have, but without much success. At the best, it may be said that we now have better records of what we are doing than we formerly had, but any little progress we make is due to the cleverness of individuals and not to the existence of a guiding science.

7 It might be objected here that numerous investigators have collected data and have made comparative tests of machines and

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tools for cutting metals. The writer needs to point only to the work of Professor Nicolson and The Art of Cutting Metals, by the late Frederick W. Taylor. However, important and meritorious as these attempts are, they do not establish fundamentals, nor were they intended to do so.

8 We might imagine that the steam engine, without the assistance of mathematics, or the knowledge of its fundamental laws, had stumbled along for a number of centuries, and, by the perseverance and ingenuity of a number of individuals had finally developed into a variety of more or less highly perfected engines, just as machine tools have arrived at that stage. We might then further imagine that some intelligent and inquisitive individual was making comparative tests of these various engines, boilers, etc., and that finally he arrived at a set of data quite new and of great interest to future designers and users of steam engines and boilers. Such a man would then have done for steam engines and boilers what Professor Nicolson and F. W. Taylor have done for cutting tools and machines. He would not, however, have established a solid, scientific foundation for the design and analysis of steam engines, such as we have at the present time. Such a foundation can only be furnished by the knowledge of the laws of nature underlying the science, and by the ability to apply mathematics to these laws, which makes the laws of nature into laws of mechanics.

9 To go further with the idea: As soon as the laws of thermodynamics were understood and had been reduced to mathematics, it became possible to imagine an ideal steam engine, which is another term for a 100-per-cent-efficient steam engine, and to show what is the maximum obtainable efficiency in any steam engine. It was therefore possible to express the efficiency of existing or of contemplated steam engines in percentage of the ideal engine. In other words, the ideal steam engine became the standard or unit of measurement. It was no longer possible for any designer or builder to think that he had produced a steam engine of the highest possible efficiency merely because his steam engine was twice as efficient as some other existing engine.

10 Mathematical analysis would soon show him that his engine was still very far from the ideal, that is, from the standard, and after building his engine a test would show him how closely he had approached in practice the product he had intended to build. In other words, he could use his theory to check up his practice. The fact

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that the inefficiency of the engine was known, left the door open for further improvements.

11 Boiler construction, and especially boiler design and furnace design, made rapid progress when engineers began to apply knowledge of physics, chemistry, and of mathematics to the art. Many times analysis showed that the results obtained were very unsatisfactory as compared with the possible results, and that there was no immediate possibility of making improvements, either because here and there was a gap in the engineer's knowledge, or else the proper materials were lacking for the building of a structure such as his mathematical vision had shown him.

12 The writer needs to refer only to the history of gas engines and, especially, of steam turbines. Though the engineer was not able to accomplish at once the things he wished to do, the problem was formulated and further developments could be grasped and used for the solution of these problems. Disastrous strains in the rotor of a turbine are no longer disastrous; insurmountable difficulties of lubrication are no longer insurmountable; and the steam turbine is with us, though at one time it was merely the vision of the scientist; or, as he is often called by those lacking in vision, the theorist.

SCIENTIFIC DEVELOPMENT OF MACHINE TOOLS

13 What are the things we should know about tools and machine tools to enable us to make these important servants of our present-day civilization follow the line of development which the steam engine has enjoyed?

14 Is it possible to develop a theory of the ideal machine tool, such as has been developed for the steam engine?

15 Fig. 1 shows two stress diagrams of cold-rolled steel, of which one specimen had a tensile strength of 95,000 lb. and an elongation in 2 in. of 12 per cent, and the other a tensile strength of 85,900 lb. and an elongation in 2 in. of 7.4 per cent. The area of each piece was $\frac{1}{2}$ sq. in. and the length between gripping jaws 2 in. The amount of work done in separating the first piece was 3500 ft-lb. per sq. in. of section, and for the second piece 2000 ft-lb. per sq. in.

16 In parting the pieces, the same result was obtained as if half the piece were removed by means of a cutting tool. Of course, this way of removing metal does not permit of controlling the shape or the finish of the remaining piece; but just the same, a certain amount of metal has been removed as effectively as if it had been done with

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a cutting tool. If this amount of metal had been removed in one minute by a cutting tool used in one of the present-day machine tools, the amount of power required to do this work would have depended on the quality of the tool and the nature of the machine; but in no case would it have been less than ½ hp., assuming a reasonable time element.

17 If the only function of a machine tool were the removal of metal, we would find that our best machine tool has an efficiency of

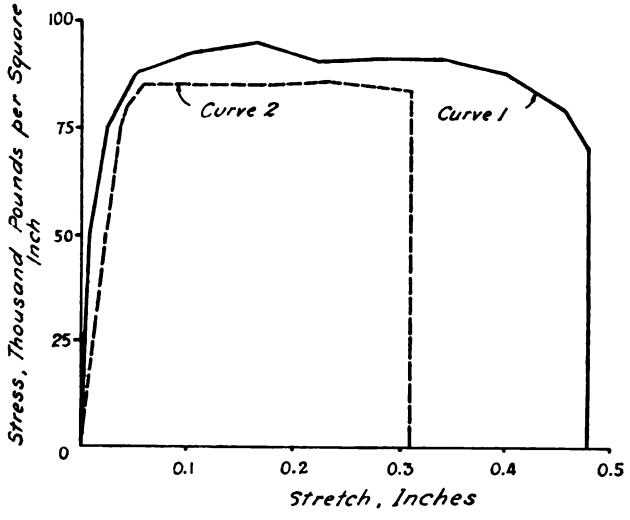

FIG. 1 STRESS DIAGRAMS OF COLD-ROLLED STEEL

from 0.12 to 0.22. Even the better of these figures is very low compared with the efficiency of other machines.

18 If chips could be removed from a piece of work by a straight pull, the ideal machine tool would be one which would remove material with the same amount of power expenditure as that required by the testing machine. While we would not expect to obtain such efficiency in practice, we would certainly aim to reach a much higher efficiency than we are now able to obtain. However, the question is whether material *is* removed by a straight pull, and this leads to the confession that the writer does not know what the exact nature of the cutting of metal is, and he believes further that he is not alone in his ignorance.

19 To the writer's knowledge, no experiments have been made which establish the true nature of the cutting of metals with a reason-

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able certainty. In The Art of Cutting Metals and elsewhere diagrams are shown of the supposed action of a cutting tool. (See Fig. 2.) The writer is inclined to believe that these diagrams represent a very good first guess; but he wishes to point out that this guess is not based on anything better than the inward vision of the authors of these various works. If this guess is correct, then the act of cutting metal is a removal of the chip by tension, and the amount of power consumed for cutting should not be more than that required by the testing machine. If this is so, the total wastage of power in all the machine shops of the world is enormous; and it certainly would be worth while to investigate this matter thoroughly, merely from the standpoint of the conservation of energy.

20 But this is not all. Every foot-pound of energy wasted in a machine tool means expenditure of power in destroying tools and wearing out machines. It seems to the writer that the problem of this wastage of power, tools and machines is of enough importance to bring it to the attention of this Society.

QUESTIONS WHICH NEED TO BE ANSWERED

21 Among the questions which should be answered before we can design machine tools in a thoroughly scientific manner are the following:

a When we turn up a narrow disk by means of a square-nosed turning tool of which the width is greater than the width of the disk, is the action of removing the chip purely a matter of tension? Or, if not, what is it?

b Does the front end of the tool have any function at all?

c How far from the edge of the tool is the point where the chip strikes the tool?

d If the action is purely a matter of pull, and the chip does not strike the top of the tool at the cutting point, but some distance farther back, then is it necessary that the cutting edge of the tool be sharp?

e What is the nature of the lamination of the chip?

f How much power is required for the actual removal of the chip, for the friction between chip and tool, and how much for laminating the chip?

g What would be the best shape for such a turning tool for this particular turning operation?

h How does the amount of power vary with the various angles of the tool?

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i If the turning operation is not as simple as the one assumed in question *a*; if, for instance, there is a side feed, such as in ordinary shaft-turning operations, how is the cutting action modified by this side feed?

j If the chip is removed by the action of the top of the tool, that is, if the front of the tool has no function, then what determines the nature of the finish of a cut?

k In what relation does the power required for the side feed stand to the power required for the actual removal of the chip?

22 A great many other questions which could be asked cannot be answered at the present time, and still more questions would naturally present themselves as soon as we had some little elementary knowledge on this subject.

ACTION OF A CUTTING LUBRICANT

23 As dark a subject as the action of the tool itself is the action of a cutting lubricant. It is a well-known fact that the use of a lubricant and the nature of the lubricant used affect both the finish and the size. A very pertinent question which might be asked is this: If the chip is separated by tension, that is, if the point where the chip begins to separate from the work is some distance ahead of the point of the cutting tool, how can the cutting lubricant affect either size or nature of finish?

24 Another equally puzzling question is: If one of the functions of the cutting lubricant is to reduce the friction between chip and tool, why should we not use a heavy lubricating oil instead of a light lard oil which has practically no lubricating qualities?

25 Or again, we might ask this question: If, as facts seem to show, the best results are obtained with a cutting lubricant which has little viscosity and which, therefore, can readily rise between chip and work by capillary action, what is the action of the oil on the separation of the chip, seeing that the oil only gets to the point of separation after the chip is separated?

26 Even more puzzling than the effect of a cutting lubricant on finish is the effect it seems to have on the size of the work. We do not see at the present time how it is possible for the lubricant to influence the size, yet that it does do this has been observed a great many times.

27 The writer had occasion to look into this matter when trying to determine the best cutting lubricant for automatic screw machines

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on small and medium-sized work. The lubricant in use was a mineral oil with 15 per cent lard oil. A certain job was selected, for which a form tool was used, and 24 screws were made with the regular compound. The screws came true to size within the limit of one-half of one thousandth. The oil was then removed from the machine and machine and tools were cleaned. The cutting compound to be investigated was substituted, and another 24 screws were made. These screws were all larger than those cut with the regular oil. Furthermore, they varied from two and one-half to five thousandths over size. The machine was once more cleaned, and the original oil put back. The screws again came uniform and to size, showing that the cutting of the first 24 screws had not dulled the tool or caused any other disturbing element to enter into the equation.

28 The fact that the cutting compound caused the screws to be oversize might possibly be explained by a difference in heating or cooling effect of the different lubricants; but how can the difference in size of screws made with the same lubricant be explained when there was no such difference with the use of oil?

29 Many other questions could be asked which cannot be answered at the present time. This should not prevent us from carefully investigating the true action of cutting metals, and determining the fundamental data, if we are interested in this matter in a purely scientific way. However, the engineer should not indulge in scientific investigation unless he feels that the results will be of practical value.

30 To be of value the results should lie in the direction of saving of power, diminished wastage of tools, and less strain on the machine; or in the direction of increased output, with or without the other advantages. That such advantages may be reached seems very clear to the author, and he wishes to outline some isolated experiments which, though not complete in themselves, point to very interesting possibilities.

31 Forged spindles of sixty-point carbon steel were roughed by a tool as shown in Fig. 3. As a rule, the tool was able to rough three spindles before a breakdown. In its broken-down condition the tool appeared as shown in Fig. 4. A hollow had been ground out by the chip, but a land of a little more than $\frac{1}{64}$ in. in width had been left at the front end, showing that the extreme front of the tool had not been in action. The experiment consisted of carefully measuring the broken-down tools and making new tools of just that shape; in other words, a tool like the old tool, but with a hollow ground in the top of the same shape, size, and location as in the old tool.

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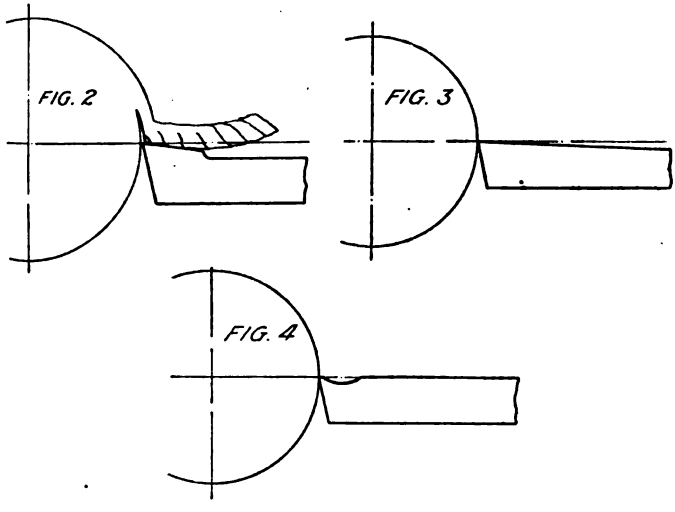
32 This tool is shown in diagram in Fig. 4. The hollow was carefully polished, and a tool thus prepared would rough from 9 to 13 spindles. Examination showed that the hollow in the tool would remain smooth almost to the last, and that a complete breakdown followed very soon after the surface of the hollow began to show scratches. No tests of power consumption were made, but it may be assumed that the power required with the old tool was more than with the new tool, as the chip did not have to bend so sharply and as the work required for hollowing out the tool was omitted.



FIGS. 2, 3 AND 4 CUTTING WITH LATHE TOOLS

33 Another interesting point about this tool was that the actual contained angle between the front of the tool and the front of the hollow was much less than we would have dared to make between the front and top of an ordinary lathe tool, especially if this lathe tool were to be used for roughing. Nevertheless, under the conditions given, this tool with the small front angle stood up better than the original tool with the large angle.

34 In The Art of Cutting Metals Mr. Taylor stated that his experiments showed no perceptible difference in power consumption for various contained angles of the cutting tool. The writer thought that this conclusion would probably be correct only for the range of cutting angles tried by Mr. Taylor. He imagined that the relation

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between contained angle and power consumption would probably be a curve of the nature of Fig. 5, and that all the experiments made by Mr. Taylor were within the horizontal part of the curve.

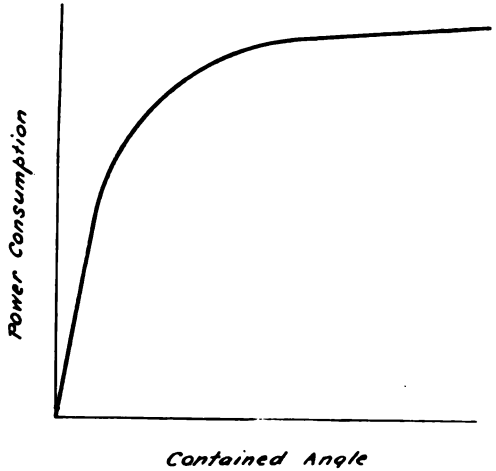
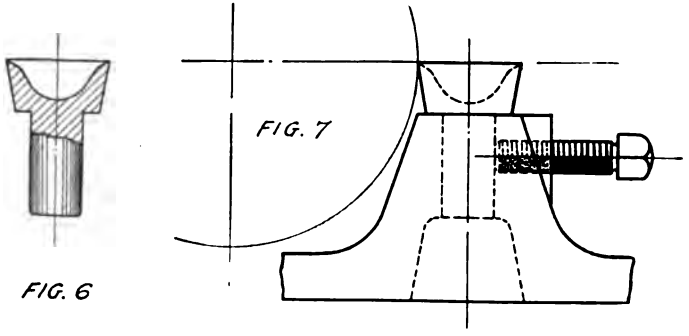


FIG. 5 PROBABLE RELATION BETWEEN CONTAINED ANGLE OF CUTTING TOOL AND POWER

35 The writer therefore set out to experiment with angles much below the angles mentioned in The Art of Cutting Metals. Realizing that an ordinary lathe tool would not stand up with much smaller



FIGS. 6 AND 7 AUTHOR'S SMALL-ANGLE TOOL AND TOOL HOLDER

angles than those used in present-day practice, he devised the tool shown in Fig. 6. This tool is a body of revolution and was held in a rigid block of metal and directly over the lathe carriage. Fig. 7 shows the arrangement of tool and tool holder used. The tool was

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used for turning, preparatory to grinding, milling-machine overarms about 4½ in. in diameter and 5 ft. long. When the tool gave out, it was turned in the tool holder so as to present a new piece of the edge to the work. In this manner from 12 to 16 settings could be made with one sharpening of the tool. The sharpening itself was a matter of circular grinding. The tool would make a very smooth cut, and without a steady rest would turn half the length of the bar with a variation in diameter of less than three thousandths. The surface

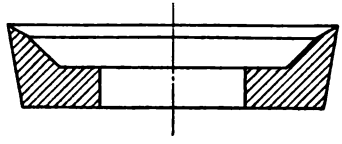

FIG. 8 EXPERIMENTAL ROTARY LATHE TOOL

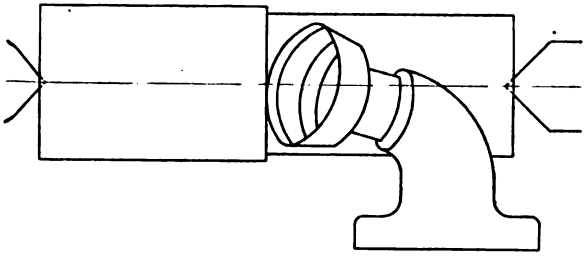

FIG. 9 ROTARY TOOL MACHINING A SHAFT

of the work was unusually smooth, and the amount required for grinding was much less than usual. Unfortunately, the lathe on which this work was done was too large and heavy to make accurate power readings for so slight an amount of power consumed, the cut being only $\frac{3}{16}$ in. reduction in diameter and the feed $\frac{1}{16}$ in. to $\frac{3}{32}$ in. The action of the tool was quite peculiar, and did not give one the impression that metal was being cut. Though nothing was learned about the relative efficiency of this tool, the writer thinks it worth while to bring it to the attention of the Society, on account of the possibilities for further investigation to which it points.

36 This matter of the relation of the contained angle to the power consumption for a given cut had previously led to the introduction of the helical cutter, where the actual angle of the tool is not small, but where the tool is presented to the work in such a manner as to have the effect of a small angle.

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37 Another experiment more or less related to the same question was an attempt to use a rotary lathe tool, such as shown in Fig. 8. The edge of this tool would bear up against the work (Fig. 9), so as to have a very slight difference in speed between the work and the tool, and it was further set in such a way as to make the virtual cutting angle very small. The result was that it became possible to use very high cutting speeds without any apparent effect on the tool. The cutting speed was limited only by the machine. With a reduction of $\frac{3}{16}$ in. in diameter and a feed of 12 to the inch, a cutting speed of 650 ft. was used for cast iron as well as for steel. All cutting was done dry. Again no attempt was made to get accurate data as to power consumption, especially as it was realized that the lathe in its present form is not well adapted to this kind of cutting tool. The chips made by this tool were not broken up and were practically solid steel bars. Furthermore, the chips as they came off the lathe were cold enough to be caught in the hand. It is therefore very likely that a test would have shown a remarkably low power consumption.

38 Though the foregoing experiments are incomplete in themselves, they do show that there are great possibilities before us, and further that these possibilities lie away from the present-day shop practice. The writer believes that it would be almost useless to try experiments along a great many lines, and by a great many experimenters, without a complete plan of campaign; and that such a plan of campaign should be based on some theory, or at least on some hypothesis; and he further believes that no such hypothesis can be developed unless we start in collecting some elementary data.

39 A few years ago, L. P. Alford, Mem.Am.Soc.M.E., who was then in close touch with the writer on this subject, approached Dr. Stratton of the Bureau of Standards with the view of having that bureau take up the first investigation of the process of cutting metal. Dr. Stratton promised the assistance of the bureau, and at a preliminary meeting a general plan of campaign was discussed. The writer believes that an order was placed for a special dynamometer for measuring the stresses in various directions when planing metal. This proceeding will probably give some valuable data, but, according to his ideas, not of a kind which will make it possible for other experimenters to use them as a basis for their own experiments.

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SUGGESTED LINES OF EXPERIMENTATION

40 The writer believes that interesting results may be obtained by following a line of experimentation such as the following:

41 An instrument should be built, somewhat along the lines of a microtome, in which a soft material is to be cut by a razor-like blade or tool. This tool should be arranged so that it can present various angles to the work, and tools of various contained angles should be experimented with. The angles presented to the work should vary as to angle of clearance, angle of rake, and angle of shear. A dynamometer, which should be part of the instrument, should register the pull required for the cut. The material to be cut should be standardized, and it is suggested that paraffin may fill all requirements; by selecting a paraffin of standard melting point we would also get a material of standard hardness. In this manner the relation between cutting angles and power required could be established over a very wide part of the curve. Though the actual figures obtained would not be immediately applicable to metal cutting, it would make it possible to find the controlling law, and, this done, it would then be possible to investigate the cutting of harder materials over a small portion of the curve and compare this portion with the corresponding portion of the curve already obtained. The same instrument could possibly be used for tests on such materials as lead, soft white metal, etc.

42 Another line of experimentation would be to arrange some machine tool, such, for instance, as a lathe, for running at a very low speed, say, 1 in. per hour; mount a steel disk on this lathe and take a cut at the circumference of this disk. In this manner the cutting action would be of the simplest kind, as the tool to be used could be a square-nosed tool of greater width than the thickness of the disk so that there would be no side cut. A moving picture taken at a high rate of speed could then be reeled off at a low speed, and it would probably be possible in this way to visualize what actually takes place in cutting metal. It would readily show whether cutting is merely the result of tension, or whether shear plays a rôle, or whether both are responsible. It would probably show whether the chip leaves the work ahead of the tool point, and whether or not the front end of the tool is in contact with the work. It would probably show many other things besides, and might be made the foundation for a number of lines of experimentation.

43 The writer believes that the time has come to try to interest

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as many engineers as possible in the subject of collecting fundamental data in regard to the cutting of metals, but rather than to suggest individually some method by which universities, industrial establishments, and engineers might be asked to coöperate, he prefers that this matter should be discussed by the Society, and would like to have this paper lead ultimately to a systematic effort in this direction, fathered by The American Society of Mechanical Engineers.

DISCUSSION

ALBERT KINGSBURY (written). It is very well known that a proper lubricant applied to tools when cutting tough metals improves the cutting, but it is not obvious how the lubricant acts, since the cutting edge of the tool is apparently buried in the metal and therefore it is not readily seen how the lubricant can reach the cutting edge.

An experimental study of this question was made by the writer about the year 1895. A mild-steel bar was mounted in a lathe, held by chuck and center rest, and was cut by a parting tool with one side flush with the end of the bar. A microscope magnifying about 30 diameters was placed for examination of the chip during formation. The bar was rotated very slowly by using the back gear and pulling the belt by hand.

Figs. 10, 11 and 12 show roughly successive stages of formation of the chip. The most important phenomenon is the fact that a crack in the metal precedes the cutting edge of the tool at all times. The crack begins at the point C in Fig. 10; it extends in substantially the direction of the finished surface of the work, as in Fig. 11, up to a certain point, where it suddenly turns outward about 45 deg. as in Fig. 12. This action is cyclical, beginning again when the point C' reaches the cutting edge.[1] The successive surfaces of these cracks form the finished surface of the work if the tool is sharp, thus giving the well-known cross-banded appearance of the tool marks; but if the tool is dull there is more or less rubbing of the tool over the surface after the cracks are formed, altering the appearance of the surface very noticeably. Oil being applied to the work, as the crack extended the oil was seen to flow into the crack, the flow being made evident by the motion of minute particles of steel suspended in the oil. Thus the oil was enabled to reach the top surface of the tool, even to the cutting edge. The principal effect of the lubricant appears to lie in

[1] Similar descriptions of the formation of the chip are given in Trans.Am. Soc.M.E., vol. 28, pp. 75 and 333.

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the reduction of friction on the top face of the tool; this increases the frequency of the cyclical breaking of the chip, shortens the chip segments and reduces the length of the cracks in advance of the cutting edge, and thus makes the finished surface smoother.

This phenomenon explains several facts regarding the lubrication of cutting tools, well known to machinists, as follows:

a Good lubricants of rather high viscosity, such as lard oil, are very effective when the cutting speed is slow, as in tapping and reaming by hand, but if the cutting speed is high, as in high-speed milling and drilling, lubricants of very low viscosity, such as soda water or soap and oil emulsions, are more effective. The lubricant is forced into the vacuum in the crack mainly by atmospheric pressure (capillarity probably being secondary if the cutting speed is high). There-

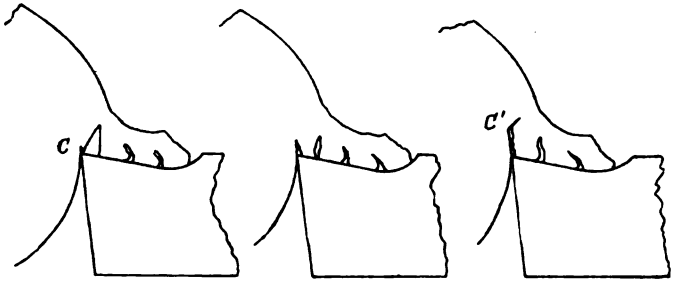

Fig. 10 Fig. 11 Fig. 12

FIGS. 10 TO 12. SUCCESSIVE STAGES IN FORMATION OF CHIP

fore, if the viscosity of the lubricant is high the cracks may not be filled fast enough.

b In the case of a parting tool cutting off a bar the tool lubricates well at the beginning of the cut, but not when the cut becomes deeper. In the deep cut the chip "upsets" and fills the slot, and therefore the lubricant cannot readily enter the cracks from the sides of the cut. It has therefore been found efficacious in large work to use two tools simultaneously in parting or slotting cuts, the leading tool being narrower than the following tool; thus both tools are fairly lubricated, the leading tool from both edges, and the following tool from one edge of each of its two narrower chips.

c In finishing cuts with broad tools the lubricant must penetrate the cracks for long distances; thus it is necessary to run slowly and to use thin lubricants such as kerosene or turpentine. More

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viscous lubricants may be used if the speed of cutting be exceedingly slow. There must be sufficient time for the lubricant to flow in the cracks from the edges to the center of the cut.

d In slab milling, etc., it is found advantageous to notch the cutting edges at frequent intervals; this breaks the wide chips into narrower ones and thus favors the entrance of the lubricant.

e In general, the more viscous lubricants are used only for slow speeds or narrow cuts, the less viscous for higher speeds or wider cuts. Even a poor lubricant, if it flows readily enough to penetrate the cracks rapidly, is more effective than a good lubricant which is too slow in getting to the spot where it may be effective.

CARL G. BARTH (written). I am delighted with the manner in which Mr. De Leeuw has pointed out the part that mathematics plays in the development of engineering, for there are as yet too many among those who practice engineering that are sadly lacking in the everyday recognition of that fact.

However, I believe that, when it comes to the art of cutting metals, we already have at our command a wealth of information that should be made more generally available and applicable in everyday machine design and machine-shop practice before we undertake to spend money and efforts in further experiments and investigations, even along the undoubtedly fundamentally sound and interesting lines suggested by Mr. De Leeuw, which at the same time do not promise enough in early results that might be immediately applied to increase the production of the present machine-tool equipment of the country through the present workers and their foremen.

Having for some fifteen years made it my principal specialty to increase the production of machine shops, I have, after all, found that the greatest diffieulty in the way of increased efficiency is that of educating workers and their foremen to see the fundamental principles underlying their work.

In my judgment the Society could do more immediate good by appointing a committee to gather together and formulate the knowledge now available, and then perhaps supplement this by further experiments with the various forms of cutting tools already in use; this committee finally instituting a regular campaign of education of the metal workers of the country to utilize the information compiled.

Personally, I stand ready to coöperate with such a committee and to give up the information I have, and to divulge the means I have

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from time to time devised to make this readily applicable in practice.

When I offer this counter-suggestion to Mr. De Leeuw's proposition, it is merely as a practical expedient to obtain results quicker, for I am sure that I believe fully as much in getting to the bottom of things as do other members of the Society, Mr. De Leeuw not excepted.

I obtained my principal training through my coöperation with Dr. Taylor, and he always said that it was better to concentrate on making use of whatever useful facts we have than to spend an uncertain amount of time in ascertaining even better facts.

H. WADE HIBBARD. As in thermodynamics, the fundamental consideration in machine designing is the ultimate constituency of matter. In a piece of steel there are millions of atoms held in relation to each other by "springs" — forces of cohesion and repulsion. If this piece of steel be heated, the forces that tend to separate the atoms are increased; if cooled, these same forces are diminished. To make a study of how to cut a piece of steel, one must consider what is being done with these "springs" connecting the atoms together.

All the forces applied to a piece of steel in cutting it, or in testing it, as Mr. De Leeuw has shown in his diagram of the tension test of a piece of steel, can be resolved into just two kinds of forces: the normal forces, plus or minus, and the tangential forces, either plain shear or rotating shear.

Upon this theory of the ultimate constituency of matter and the forces which hold atoms together, some of the things that puzzle us in machine-tool designing are made more clear. For example, the author asks, "When we turn up a narrow disk by means of a square-nosed turning tool of which the width is greater than the width of the disk, is the action of removing the chip purely a matter of tension? Or, if not, what is it?" No, it is not purely a matter of tension, because according to the above reasoning both normal and tangential forces are acting on the "springs" holding the atoms together. Also, "What is the nature of the lamination of the chip?" Its nature is almost purely the action of the tangential force upon those "springs" holding two adjacent layers of atoms together.

"We do not see at the present time how it is possible for the lubricant to influence the size, yet that it does do this has been observed a great many times," the author states later. That, I believe, if we think of these two kinds of forces, the normal and the tangential, means that by lubricating the top of the tool we reduce the normal

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force necessarily. In other words, we reduce the compression of the chip in the direction of the length of the chip, and that of course has its effect upon the size of the turned part which is left, after the part has been turned by the tool.

R. POLIAKOFF[1] (written). In Par. 32 the author refers to a tool which he shows in Fig. 4, and mentions that this tool broke down very soon after the surface of the hollow began to show scratches. I do not know what was the plan of the tool, whether it had a round edge or not, but the scratches might have been attributed to the following reason:

If you take the ordinary round-edge tool (Fig. 13) with the ordinary angles of front rake, side rake and clearance, you will find by a very simple mathematical analysis that when the front rake is less than the side rake, as it usually is, the cutting angle then changes from point to point of the edge. I assume here that the chip and all its elements go off the bar at a right angle to the cutting edge at the respective point. It will have one value at the plane *ab* (i.e., at the plane of the front rake), a lesser value at the plane *bc* (side rake), and intermediate values at points *de*, etc.; and if the respective values of the cutting angles are laid off at the corresponding different points *a*, *d*, *e*, *c*, of the cutting edge, then these values will change like the curve $a_1d_1m_1c_1$, Fig. 14. In other words, the angles will first decrease, then go up a little, then decrease again until they reach the lesser value cc_1, corresponding to the plane *bc*. With an ordinary round-edge tool and the ordinary usually accepted angles of side and front rake, they change in a curve which has some peak points.

If it be assumed that the chip consists of elementary chips, each element going off the bar at right angles to the cutting edge, then these different elementary chips have to descend on inclined planes with changing angles, and necessarily one elementary chip is either retarded or accelerated in its downward movement by its adjoining chip; and this retardation or acceleration necessarily must create inner friction and cause the different scratches on the hollow of the tool, every single scratch being the mark left by an elementary chip.

As I stated at the beginning, if the scratch to which Mr. De Leeuw referred can be attributed to the reasons just cited, then, in my judgment, the following procedure could be suggested to avoid these scratches and prolong the life of the tool:

All the cutting angles must be equal at all points of the cutting

[1] 111 Broadway, New York, N. Y.

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edge, starting at the *ab* plane and terminating at the plane *bc*; and in order to achieve this end the quadrant *adec* should not be a plane but a quadrant of a circle drilled out by a drill with its center point at *b* and having a radius *ab* equal to *bc* and its cylindrical body projecting in the line *adc*. In this way all the cutting angles would be equal all the way through from *a* to *c*, just as in the case of a straight-edge tool.

Of course, this calls for another way of preparing the turning tool altogether, both with regard to machining and grinding, but this can be very easily arranged. In fact, I introduced such a tool in the

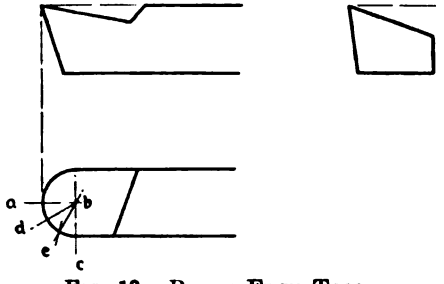

FIG. 13. ROUND-EDGE TOOL

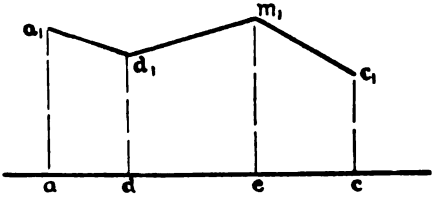

FIG. 14 VALUES OF CUTTING ANGLES

Laboratory of Technology at the Technical Institute, Moscow, Russia, some two and a half years ago, and have also designed some grinding attachments to grind the hollow produced by the drill.

I started to make some experiments with a tool so designed, but had to discontinue them on account of being sent over to this country in connection with some war problems. I hope, however, that I shall be able to resume the experiments in the near future, and shall be glad to report to your Society the results obtained.

I also made some dynamometer tests with such a tool, but these tests are likewise in an unfinished condition as yet.

Referring to the circular tool of Mr. De Leeuw, Par. 35, I believe that he originated this tool about two and a half years ago. I do not

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know how much experimenting has been done with this tool in this country, but I may mention that as soon as I read about it in the *American Machinist*, where it was originally described, I prepared a tool along the same lines with the object of making some experiments, but, as already stated, I had to leave for the United States and therefore could not make them.

However, I published an article in one of the Russian technical magazines describing the construction of this tool, and, based upon this description, a few tools have been prepared in the Ijev Rifle Works, in the Ural Mountains, in northeastern European Russia. When I visited these works in 1915 I was shown the results of their experiments, which proved to be very satisfactory, both with regard to speed and life of the tool. I have sent these facts to the Russian magazine, *Vestnik Ingenerov*, for publication.

Referring to Mr. De Leeuw's Suggested Lines of Experimentation, Pars. 40–42, I fully agree with what the author says, but can easily see some objections from the so-called practical viewpoint of practical shop men. Mr. De Leeuw suggests that these experiments should be made at low speeds, but whatever the results of such experiments may be, the ordinary shop man will probably say, "That's all right — it may be all right in theory, but how about the practical side, where the results of such experiments are quite different?" They will doubt if the results of such experiments can be fully applied to practice.

In connection with this I may mention that very few experimental data have been published along the line of cutting with fine cuts, although a little has been done in this direction.

Edward Herbert, of Manchester, England, has been working along such lines for some time, and has invented a special machine for taking very fine cuts from a hollow tube. He has published some of the results of his experiments and they are very interesting, especially with reference to the cut, as they show that a finishing tool fails quite differently from an ordinary roughing tool.

In the roughing cut, when you increase the speed, leaving all other conditions equal, the time of the endurance of the tool decreases, something like curve *ac*, Fig. 15, in which the abscissæ represent the speed and the ordinates the endurance time. In the case of the finishing tool, however, the endurance curve is something like the curve *abcd*, Fig. 16, with some peaks in it, which means that when you increase the speed of the finishing cut the endurance time may increase up to a certain limit, and then will start to decrease with a

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further increase in the cutting speed. If the cutting speed continues to increase, the endurance time may go up again. From this one can draw the conclusion that there is probably a certain speed which is the most profitable for working so far as endurance of the tool (and, as experiments show, also the appearance of the machined surface) is concerned.

When Mr. Herbert presented his paper on this subject some three or four years ago, he met with the same objections to which I have

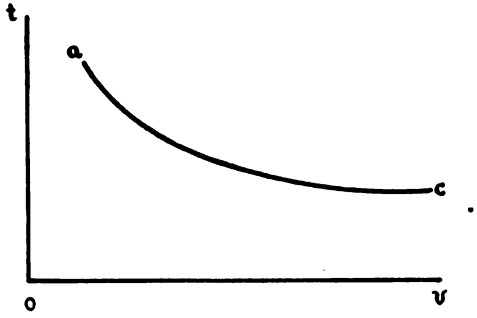

FIG. 15. ENDURANCE TIME OF TOOL IN ROUGHING CUT

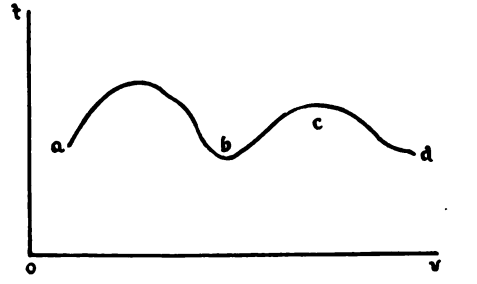

FIG. 16 ENDURANCE TIME OF TOOL IN FINISHING CUT

just referred, i.e., that these experiments may be of much theoretical value but are very doubtful so far as practical results are concerned.

In order to meet these objections to a certain extent, I made some experiments on finishing cuts, but in a quite practical way and under conditions absolutely identical with those prevailing in ordinary shop practice. It would perhaps be out of place to go into too many details of these experiments at this time, especially as I have already presented them in a paper before the Institution of Mechanical Engineers, in Manchester, an extract of which was published in the *American Machinist* some ten months ago.

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Suffice it here to say that these practical experiments fully confirmed the results of Mr. Herbert's experiments made under conditions different from shop practice.

Therefore I can most assuredly say to shop men that practice and theory go hand in hand together, and if the theoretical experiments are conducted on the right lines, they are sure to yield valuable practical results.

A. LEWIS JENKINS said that, at the suggestion of Mr. De Leeuw, about three years ago a set of stationary cup-shaped lathe tools similar to the tools shown in Fig. 6 in the paper was made at the University of Cincinnati. Something like 600 tests were made to compare the power required for the De Leeuw tool, as they called it, with that for a standard Taylor tool made by the O. K. Tool Company.

The cutting angles were varied from 16 to 90 deg. and the diameters of the tools from 1.25 to 1.4 in.; the work specimen was a piece of steel 4 in. in diameter and 30 in. long. The machine employed was a LeBlond 21-in. all-geared-head lathe.

The tests were made by using a cradle dynamometer, and after taking the readings for one tool at a given feed, depth and speed it was removed and the other tool put in place without changing the speed, feed and depth of cut. The conditions of operation were therefore exactly the same for both tools.

The De Leeuw tool gave a higher finish than the Taylor tool. The De Leeuw tool made no chatter marks when the work was greater than 2 in. in diameter and the cutting angle less than about 80 deg., even on the heaviest cuts taken. The Taylor tool chattered on all diameters when taking the heaviest cuts. The results of these tests showed that a De Leeuw tool having a 40-deg. lip angle required about 90 per cent of the power it took to drive a Taylor tool under the same conditions. For cutting angles greater than 60 deg. there was practically no difference in the power required for the two types of tools when operated under these conditions. The feed varied from $\frac{1}{64}$ in. to $\frac{1}{8}$ in. and the depth of cut from $\frac{1}{32}$ in. to $\frac{1}{8}$ in.

LEON P. ALFORD said that a recent question before the Research Committee of the Society was, "What can this Committee do at the present time which might have a beneficial effect in helping this country at war?" One of the sub-committees brought in the suggestion that very little had been done in the direction of a study of the

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action of cutting tools and the cause of chip formation, and it was decided to concentrate the efforts of the Committee upon that topic. As a member of the Research Committee he asked that Professor Jenkins place in the Committee's possession all the information he had in regard to the series of tests described, and that Professor Poliakoff do the same thing in regard to the investigation he had made and from his experience with this tool in the Russian rifle works.

FREDERICK A. WALDRON thought that in all this work there was an eternal fitness of things, and in his remarks led up to a classification of machine tools, this classification taking the following form: (1) machines of convenience; (2) machines of precision, and (3) machines of displacement. Machines of convenience were to be used where the convenience of the operator was paramount; machines of precision for toolroom work requiring both convenience and precision; and machines of displacement to remove the maximum quantity of metal in minimum time consistent with the life of the tool and the machine.

ARTHUR J. BAKER, referring to the type of turning tool shown in Fig. 4, said that about eighteen years ago, in England, his firm was making tools for turning shackle pins for the Admiralty. These were large tapering pins, say, two or three inches in diameter at the small end, and running up from six to twelve inches in length, and were turned on rather rough lathes. When they used the standard type of tool the machine would not take the cut at a feed sufficient to enable them to produce the pieces in the time that they felt they should be produced in; so they slowed the machine down but failed to reduce the feed. They then made a flat-topped form tool for the roughing operation, and sunk into its top surface a half-round cutter which left a flat lip or land about $\frac{1}{32}$ in. wide on all of the cutting edges. This construction reduced the friction and enabled them to take a cut of almost twice the average that they were able to when using the standard type of cutter.

In regard to the circular turning tool shown in Fig. 9, he had been instrumental in placing a number of those tools in various lathe plants around the country. Some of the users employed them in experiments, and some, he rather thought, did not believe they were very practical and did not go further with them; but the Pennsylvania Railroad, at Altoona, used them on some of their larger rods,

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with quite satisfactory results, except for this one drawback: that the circular tool could not be used on any job where it was desired to cut up to the shoulder, because the retention of the rather thin cutting edge between the chip and the work usually caused a breaking as the tool was withdrawn. So that the real virtue of a tool of that kind was confined to its use on work that enabled one to pass quickly across the surface. The American Blower Company, of Detroit, had used one of these tools for turning pulleys, and the results were highly satisfactory indeed.

The cutting speed used in turning the Pennsylvania Railroad rods was about 65 ft. per min. They made no attempt to get high speeds. The cast-iron pulleys turned at the American Blower Company were run at approximately 1.30 ft. per min. — the iron was tolerably hard — which was the highest speed they had been able to use.

CHARLES FAIR (written). I agree with Mr. De Leeuw that we will not get very far with our investigations so long as these investigations and tests are conducted by individuals in a more or less haphazard sort of way, and almost invariably by some short-cut method which usually results in not getting the necessary data that would make the tests of any value. It is too bad that more methodical consideration is not given to such investigations. I know of no body better fitted to undertake this work than our Society, and would therefore like to suggest that we should carefully consider the subject with a view to the laying out, if possible, of some definite plan of action not only to be followed by the Society but elastic enough to be useful to the individual investigator who cares to cooperate with the Society. Much time is being wasted by a repetition of what might almost be called standard tests, while little thought is given to that which might seem to be secondary, but which, in reality, might be of great importance.

While I think that some of the questions raised by Mr. De Leeuw might be satisfactorily answered, I am afraid that it will require considerable investigation before one may venture on even an intelligent guess as to the answers to a number of others.

LUTHER D. BURLINGAME said he would like to offer a resolution, based on the idea that Mr. De Leeuw had brought forward a work of real importance and a work well worthy of attention, that the meeting urgently request the Council of the Society to place suitable funds

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at the disposition of the Research Committee in order to carry on experiments in the use of cutting tools, along the lines referred to in Mr. De Leeuw's paper.

RALPH E. FLANDERS asked whether it would be possible to secure the coöperation of Mr. Barth and his associates with the Research Committee, or any other proper committee that might be formed. It would seem to be possible, for instance, to put the information on lathe tools, speeds and feeds that was obtained by Mr. Taylor's work into some concise form so that it could be used by engineers anywhere in the machine shops of the country. It seemed to him that this would be a simple, direct and patriotic service that could be rendered to the country just at this time.

RICHARD T. WINGO thought that one of the things the Society could do to advantage was to organize the machine-tool shops, with a view to exchanging information regarding tool equipment and methods. His reason for saying that was that it would be found, in going into one machine-tool shop, that it was doing a certain thing in a certain way, but if a competitor came along, very frequently it would be found that that shop was under lock and key because it did not want to show a competitor how it was doing its work.

Of all the branches in mechanical lines the automobile had brought about the most remarkable results, and it had been done by one concern showing another what it had been doing in every detail.

THE AUTHOR. Professor Hibbard has gone several steps further than I would want to go at the present time. We do not yet know very much about the ultimate constituency of matter.

In answer to Professor Poliakoff's question as to the shape of the tool that was used, I would say that it was of the square type, with a slightly rounded corner and with an angle in both directions; a groove was ground close to the front edge and in the direction of the feed. Most of the metal came off at right angles to the direction of the feed. The scratches were all in that direction.

There was no particular way in which the tool would fail; it would sometimes fail near the point, as if the tangential flow of metal would cause it, but more often it failed in the other direction. The importance of the scratches was simply this: that almost immediately after they began to form the tool would fail, showing, therefore, that the greatly increased friction over the surface of the tool caused its

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breaking down, probably on account of heat, and possibly on account of the increased force there.

Professor Poliakoff also said that the idea of a very low speed would not appeal to the man in the shop. From what I know about the man in the shop, I would not think that any experiment of that kind would appeal to him. The fact is, the man in the shop is not inclined to do experimenting; he is very much opposed to it.

I am heartily in accord with Mr. Waldron's idea of a classification of machines. It is getting time that we should know what we are talking about. We are talking about machine tools, about a lathe, for instance, but a lathe may be used for so many different purposes. However, I believe that a very large portion of the work done by machine tools in modern industries is work of displacement. The lathe, as constructed at present, is utterly unfit for using a rotary tool. The conditions are so radically different that I do not believe the lathe can be used as it is at present. In the first place, a very much larger proportion of the power consumed has to go through the lead screw. In the second place, in order to get the best results the lathe should run at a very high speed. And, running at a high rate of speed with a bar perhaps five feet long, running 1350 revolutions, is a very dangerous proceeding. If the end should run off the tail center there would be a disaster. Furthermore, it is not possible to run the ordinary lathe at the speed required for that tool. One of the things to be done would be to arrange a lathe so that such a tool could be used to advantage. Still another thing: under the tests described the carriage traveled 47 in. per min. Now, at that rate it is not possible to throw out the feed by turning the knob — it is possible, but not within half an inch. In other words, if the left hand should fumble with that knob for just an instant — one second, it would run up against the dog or faceplate and there would be something doing! In regard to what was said about slide rules, that is really a matter which I do not care to discuss; I do not wish to say whether a slide rule is going to improve the performance of the lathe or not; in fact, I know it does, but that is a matter of management — a matter of the use of the knowledge we have at the present time. It was very far from my idea to suggest that we should not use the knowledge we have; the paper was not aiming at that at all. I neither advocated neglecting to use the knowledge we had, nor did I advocate its use. To advocate not using the knowledge we have would be a piece of foolishness, and to advocate using it would be almost an insult to the engineers present. What I am urging is to gather up knowledge.

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Whether it is practical at the present moment or not has nothing to do with the question. We all know that before knowledge can be made practical, the knowledge must be available. There is no use in talking about some particular application of the thing when we do not have the thing. The main thing I would urge is that we should go forth and get it, and that we should try to find out some of the elementary knowledge about the art or science of cutting metals. Personally, I feel that when we have that knowledge we will be able to use it. The American nation has had conspicuous merit in the application of knowledge, but it has not made a mark in the gathering up of knowledge. I have no doubt whatever that there are a great many men in this country who are just as capable of finding and gathering up knowledge as there are abroad, but I believe that heretofore we have had the habit of looking at the mere gathering up of knowledge as something that has no particular value, as merely a sort of a plaything for the professor who sits in his study and does his thinking and plays with his thoughts, and then writes it all down in a book and the book is put somewhere on a shelf in some library and is forgotten. But that should not be the case. Of all the knowledge that we gather up, there may perhaps be a certain percentage that is not immediately usable, but I cannot think of any great or even fairly notable discovery in science that has been made that is not at the present time employed in actual practice. If Professor Roentgen had first said, "Let me see how I can apply X-rays," and then, after he had made out how he could use them, had said, "Now, let me see where that X-ray is — let me hunt it up," we would have had no X-rays. If Professor Becquerel had first asked himself what he could do with those peculiar Becquerel rays, and how he could use them for transmitting knowledge from one end of the earth to the other, he never would have found the Becquerel rays; the Hertzian waves would never have been found, and we would not have any Hertzian waves at this time. Those men simply gathered up the knowledge, and then there were other men who were, perhaps, working on different lines who took that knowledge and applied it. So that my plea is for definite knowledge about tools and cutting metals, and I have a profound belief in the ability of the American engineer to apply that knowledge after it has been found.

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No. 1590

MACHINE-SHOP ORGANIZATION

By Fred G. Kent,[1] Cincinnati, Ohio
Non-Member

This paper seeks to set forth the fundamentals of a typical machine-shop organization.

It begins with a discussion of the methods for introducing changes in the way of reorganization, has something to say about the kind of man who does the job and how he gets started; then goes on to an analysis of the organization by departments.

Each department is described so as to show its importance, its special duties and responsibilities, and its relation to the whole.

Fig. 1 shows how this analysis is developed.

IN this paper it is my purpose to outline briefly the basic structure of an organization for a shop building the average line of machinery. I shall not touch at all on the commercial side of the organization, such as sales, advertising, financial, and purchasing, but will confine the paper entirely to the manufacturing end.

2 As all my experience has been with concerns in operation for some years before my becoming connected with them, I have always had the advantage of having considerable high-grade material, both in the way of men and equipment, ready at hand to work upon, which accounts for some of the ideas expressed below.

3 While I have been associated with some very large concerns, I would rather these remarks apply to the shop employing 600 men or less, for a shop of this size, from the very nature of its growth and the volume of business transacted, has just as many, if not more, obstacles to overcome as the larger plant, and is usually in no condition financially to set aside any large sum for betterment work. For this reason it is necessary in a business of this sort to plan any forward move with the greatest care, in order that there may be sure profit in each change made and all such changes may take place at such times as to cause no interference with getting out the regular product.

[1] Lodge and Shipley Machine Tool Co.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of The American Society of Mechanical Engineers.

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4 This of course means rather slow progress, which is apt to be discouraging to the man who is anxious to see things go, but, on the other hand, it has a decided advantage in the fact that the evolution is so gradual that there is very little opposition or unfavorable comment from foremen or workmen inclined to discredit innovations. This in itself is a very important factor toward any reorganization scheme, for, notwithstanding arguments to the contrary, the stability of any shop system depends very largely on wholehearted coöperation, from the chief executive clear down the line to the sweeper.

5 Some time ago James Collins made the statement in a magazine article that "during the next few years some of the largest profits in American industry will be saved out of operation. Heretofore our profits have been made, but saving a profit is a different thing altogether." I quite agree with this, and my work for several years has proven to me that hundreds of small details are allowed to take the wrong course simply because they have always gone that way. We have all of us been too much concerned in systems of paying wages, with the object, of course, of getting more work at a lower cost. Sometimes straight piece work has been adopted and again it might be some one of the several forms of the bonus or premium plan, and in nearly every one the feverish desire to get something started has precipitated action without proper planning and has brought about useless waste of time and energy, and, in many cases, ill-feeling among the workmen. If for no other reason than that of harmony, let us leave the time-study and wage-payment schemes until we feel sure that we have very nearly gone the limit in stopping other leaks.

6 My first point is that wage payment, premium schemes, bonus arrangements, etc., should be the last point of attack rather than the first.

7 Let us suppose that we are going about the reorganization of such a shop as I have mentioned. What is the best course to take? It is my opinion that the easiest way out and at the same time the one most profitable, is for the directors to place a man of proven executive ability at the head of a military or line type of organization, giving this man plenty of time and a free hand to work out the solution of their problems. This arrangement will prove successful more times than any other.

8 The selection of a title for the man who is to lead the way is a matter of considerable importance, and, if possible, the position should be a newly created one. For instance, if the chief executive

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has been known in the past as a supervisor or general superintendent, let the new position be that of Works Manager. Such an arrangement enables the old superintendent to retain his prestige with the men until it may be deemed proper to make a change, and it also starts the new man off with more of a punch.

9 The question is often asked: "Where can we get the right sort of man?" — and the answer is that he is not half so hard to find as is generally thought. Many a time the man is already in the organization, but he has been so thoroughly "hog-tied" that he has never had a chance to show what was in him.

10 Assuming that the right man is on hand ready to take hold, if he is a newcomer in the concern he should be given at least two months to get acquainted — first with the owners, carefully analyzing their statements of troubles. After two or three days on this end of the job, let him go out into the shop and get acquainted with the department heads, encouraging them to talk of their troubles, and if possible have them express an opinion as to the causes of failures in the past. Let him drop into the works in the evenings and cultivate even the watchman's acquaintance. He will find that long hours spent alone in the shop are frequently productive of leads of value. Let him walk through the machine and erecting departments on Saturday afternoon and an occasional Sunday for a time, looking into every corner and cubbyhole. The number of points that can be brought out in a survey of this kind will surprise one who has never tried it. All this is a mere matter of getting acquainted with the job, and it goes without saying that if this point is neglected all future work will rest on an insecure foundation.

11 The location of the headquarters of the new works manager should be open to all shop employees and the men encouraged to come in. It should, therefore, be in the place most accessible to the works and it should also be perfectly plain in its appointments. The business to be transacted with the shop can be carried on over common oak desks and bare floors with a far better feeling than it can over mahogany furniture and oriental rugs. The average workman does not care to come with his greasy shoes, soiled clothes and dirty face into an elegantly appointed office to talk about the things the manager ought to know about, and when he does, he is self-conscious and ill at ease, and goes away without half stating his case and irritated because of a feeling that he has been put at a disadvantage.

12 Now when the works manager has learned to find his way around without a guide, and the men in the shop have learned to take

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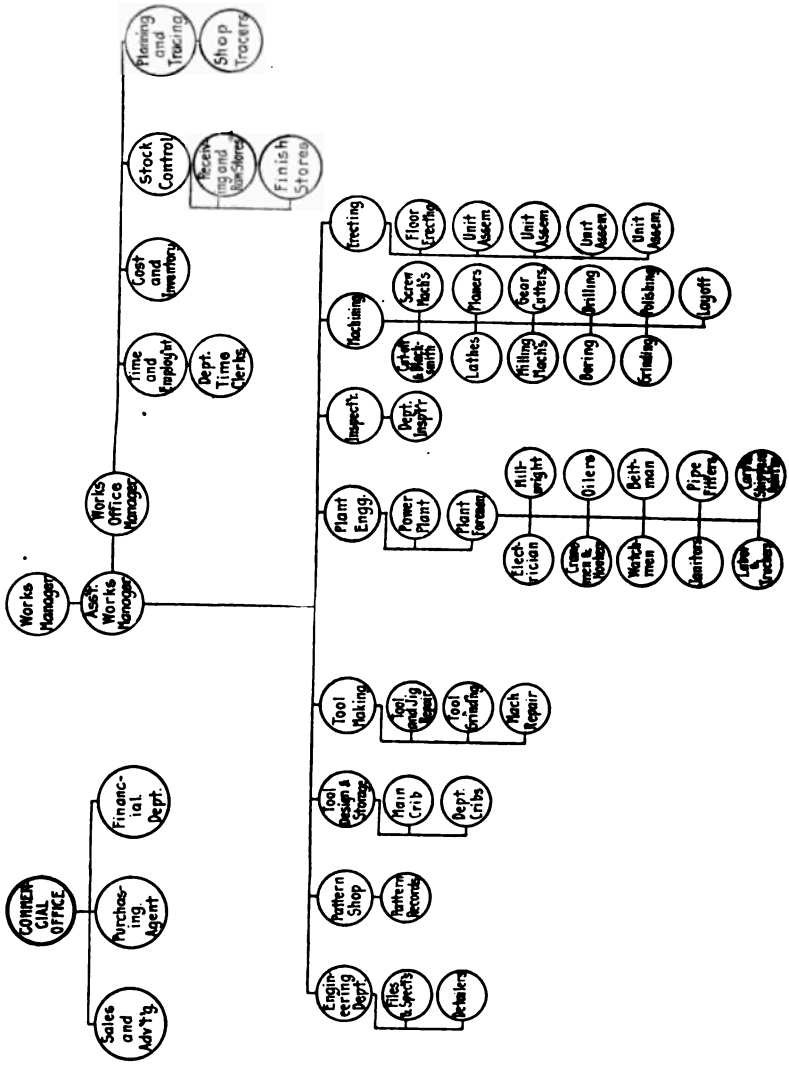

FIG. 1 ORGANIZATION CHART

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his presence as a matter of course, let him start the first forward move by analyzing his shop conditions and personnel, and laying down a definite organization. Of course, any organization that he may plan in the start will be changed in minor details many times, but there is no reason why the main structure should not remain practically the same as originally planned.

13 It is understood, of course, that what one is seeking for in this move is to subdivide the entire plant into a number of different units, placing a definite responsibility upon the head of each unit, and it is understood that the heads of these units will be respected in the positions that they hold, or, in other words, there must be no splitting of authority or going over one's head with orders of any sort. For instance, the giving of orders directly to a workman by a general foreman or anyone else higher in authority is a serious breach of discipline, as it soon weakens the foreman's standing with the men to such an extent that he soon becomes useless as an executive. The same thing holds good in a much greater degree in the relationship of the owners to the head of their manufacturing operations. This may seem an insignificant point to bring out in a paper that is only touching the high spots, but I believe that many shops in need of reorganization owe 90 per cent of their troubles to the failure to fix definite responsibility and live up to it.

14 This subdivision of the shop is readily visualized by means of an organization chart (Fig. 1) which will give the layout of responsibility as well as the physical layout. In making up this organization chart I have found that the easiest way is to use round metal-bound cardboard tags distributed on a large drawing board.

15 The first tags made out should contain the names of the main departments. The average typical shop should have the following departments: Works Office, Engineering Department, Pattern Shop, Tool Design and Storage, Tool Making and Repair, Plant Engineering and Power, Machinery, and Erection.

16 This division of the shop is merely typical and it must be understood that all sorts of variations are necessary, due to the varying factor of the personnel from which the organization has to be made. I might say here that I am a very strong believer in using the personal material at hand rather than replacing the old employee by new help.

17 The next step is to add to each department tag the name of the man who is selected to have charge of that department. With these tags spread out on the drawing board, with two more tags for

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the Works Manager and an Assistant Works Manager, and a number of smaller tags for the subdivisions of the major departments, the general shop organization begins to take shape.

18 I want to insert here that the assistant works manager should be capable of assuming the work of the works manager in the latter's absence from the plant, and both the works manager and the assistant should have as few routine duties as possible. Their time should be spent in planning improvement and in bolstering up the weak points in the organization. A great many men get the idea that organization once done is done forever. On the contrary, the only organization that is final or complete is a dead one. I have cleaned up two plants after several firms of so-called efficiency engineers had had a shot at them. They had gone away after a time leaving a mass of charts, forms and card indexes which were supposed to have accomplished a complete reorganization. Even if this reorganization was sufficient for the needs of these plants at the time they left, which it was not, it would be foolish to suppose that it would automatically administer affairs for an indefinite period. The business that is managed by live men is always subject to profitable changes.

19 The balance of this paper can be covered by an analysis of these departments. First, the Works Office. This, to my mind, is the most important division of all; if I had to choose between a poorly equipped shop with a good works office and the best equipped shop in the world with a poor works office, I would choose the former. The head of this department should be an understudy of the assistant works manager.

20 The greatest fault in choosing a man for the head of the works office is getting a man who is too one-sided. Often an accountant is chosen, and he fails to appreciate the true relationship of the office to the shop; if a man of purely shop experience is chosen, he fails to understand the importance of records. He should therefore have some accounting as well as shop and engineering experience. He should have an imaginative and inventive mind to originate new forms and apply mechanical devices which insure greater accuracy and reduce the amount of labor.

21 In this short paper it is impossible to go into details as to the possibilities of this position, but I have in mind a case where a man of this sort, through clever adaption of methods to the needs of his office, in two years' time reduced a working force from thirty-five to twenty men.

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22 The Works Office is divided into four divisions: *first*, Time and Employment; *second*, Cost and Inventory; *third*, Stock Control and Receiving; and *fourth*, Planning and Tracing.

23 The Time and Employment Department takes care of hiring men, application files, changes in wage rates, etc., and making up the payroll. This section also has charge of the department time-keepers maintained for the sake of accuracy of records and efficiency of foremen. The workman or foreman is never allowed to handle his own time records. In conjunction with the employment department, I have found it a benefit to the shop at large to employ a medical man and install equipment to take care of all injuries and illness that may occur in the shop.

24 The Cost and Inventory Department should be able to show the cost of any job at any stage of operation, and the exact profit from the complete job. It should further be able to analyze any of the figures into direct wage, burden, material, etc., and also its records should show by comparison all previous jobs of the same sort, and, without being called upon, it should call the attention of the works manager to any unusual discrepancies in these comparisons. There should be the same type of comparison of the various accounts of indirect expenditure.

25 The Stock-Control Department should have charge of issuing shop orders, ordering from purchasing agent all raw material and finished material in proper quantities and in sufficient time to get the finished product on a specified date, receiving raw and finished stock, as well as storage of parts finished in the shop. Special effort must be made to secure accurate accounting of all material, as this is just as essential to the right operation of a shop as the cash balance is to a bank.

26 The Planning and Tracing Department establishes the order of progress of work through the shop. This department must be able to show the location of every job in the shop within a half-hour of its movement from one operation to another. It is possible to accomplish this by very simple methods. Two or three men following these records and kicking loose the dead ends, were able in one shop to lessen the number of jobs in the shop at one time from over 25,000 to less than 7000, in addition practically eliminating the shortage of finished parts at the point of erection. When the time is ripe for time study and the establishing of standard times, this will be one of the functions of the planning department.

27 In the Engineering Department all engineering information

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regarding specifications has its beginning. The best arrangement is to separate the Chief Engineer, who is responsible for designs, entirely from that section which issues the specifications to the shop. The chief engineer then has charge of the design and improvement of the product, including action on all changes suggested from any source.

28 The specification section takes on the work of detailing, tracing, checking, indexing, filing, making blueprints and parts lists, making bills of materials and issuing them to departments requiring them. Standard sizes should be established for all drawings and the straight numerical system of identification used. For detail work one piece only should be shown on a sheet. Details should be drawn to scale, close measurements expressed in decimals and the working limits stated on each drawing. Dimensions should be so complete that the machinist does not have to do any figuring in order to find any measurement.

29 Assembly drawings must be furnished for each assembled unit. The assembly drawing must show the piece number of the details that go to make up the assembly, but without any dimensions of these parts being shown. I have found that showing several details on one sheet or working from dimensioned assembly drawings is bad practice. They will slow up the work in the shop and are the cause of a great deal of scrapped work.

30 New designs should be gone over by the chief engineer, chief draftsman, works manager and his assistant before being detailed, and the detail should be criticized again before going to the planning department. It is much easier to rub out mistakes on the drawing than it is on a casting in the shop.

31 The Pattern Shop has the making of new patterns and the repairing of old ones, also the pattern storage and location records of patterns in the works and at the various foundries. I wish to make a point of the equipment in the pattern shop, which should be the best obtainable. There is no profit in working high-priced men on weak-kneed tools. If patterns are to be used for quantity production, ease of molding and long life should be considered in building them, but where a limited number of castings are to be made, no more time should be put on them than absolutely necessary. Lack of attention to either one of these details has caused large losses to many concerns.

32 The Tool Design and Storage Department takes up its work at the point where the drawings for parts to be manufactured leave the planning section of the works office. Any new jigs or fixtures

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required for the sake of interchangeability or economical manufacturing are designed and ordered by this department. This department is also responsible for storage, indexing and checking of jigs and smaller tools in the tool cribs in the shop, and requisitioning the purchase of small tools — taps, cutters, drills, emery wheels and so forth.

33 The Tool-Making Department will build all new jigs and keep up repairs on old ones. The sharpening of all small tools, milling cutters and reamers must be done in this department, and under no consideration by the workman using them.

34 The Plant Engineer in conjunction with the power plant is an arrangement seldom found in any shop. By a plant engineer is not meant a steam or electrical engineer, but a man with mechanical-engineering training who is responsible for the physical upkeep and improvement of the plant and the use of power. The opportunity which a man in this position has for saving money and increasing output is very great. The locating of all machinery, shop furniture, line shafting, piping and wiring must pass through his hands. In one shop the writer had charge of, the load on the power plant was rapidly going beyond its capacity and steps had already been taken to install new equipment that would cost many thousands of dollars. By installing ball bearings and rearranging shafting the plant engineer was able to reduce the load over 40 per cent at a cost of 15 per cent of the cost of a new power plant. There was also the saving in the cost of operation which the new power plant would have entailed.

35 The Plant-Foreman's Department is answerable to the plant engineer. The work that the plant engineer performs is usually taken on in a more or less slipshod manner by the heads of various other departments. He should have charge of the millwrights, oilers, belt men, pipe fitters, electricians, carpenters, crane operators, hookers, laborers, watchmen, janitors and shippers, and is responsible for the cleanliness of the plant, both inside and out.

36 The Inspection Department must be answerable to the works manager or his assistant only. In no case should the inspectors take instructions from any of the machine- or erection-department heads. They must pass judgment on all work in process as well as the finished product. The inspection may be carried out either directly on the floor or in a centrally located inspection room. This depends more or less on the nature of the product.

37 The Machining Department may have one general foreman, with his assistants in charge of the subdivisions. These assistants

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have instructors under them whose duties comprise seeing that jobs are properly set up, tools properly selected, and proper feeds and speeds are used. There should be about one instructor for every ten men. Supervision of the machine work must be entirely separate from the erecting department.

38 The writer is a firm believer in placing machines of a kind together; that is, lathes in one section, drilling machines in another, and so on. It keeps down the amount of the investment. It makes a better-balanced condition, and the work goes to a foreman who knows more about that particular operation than an all-around man can ever hope to know.

39 The possibility of improvement in the various operations of the machine shop is never-ending, and the changes in machine tools are continuous, which is a fact that the works manager and his assistant should never lose sight of. Any new tool that promises more economic production should be thoroughly tried out and, if satisfactory, the old tool should be immediately disposed of, as it is cheaper to scrap a tool than to operate at decreased efficiency.

40 The Erection Department should have a general foreman, with the various units of assembly placed under his assistants, as, for instance, in a lathe shop there would be a head and tailstock department, carriage and apron department, etc., and a final erecting department of the sub-assemblies into the complete machine.

41 As I have already stated, this paper just touches the high places, but it outlines the basic structure of an organization for a medium-sized shop building the average line of machinery.

DISCUSSION

J. M. Spitzglass related an experience in shop organization or reorganization which was rather the opposite of that cited in the paper.

In this case the shop was a very small one, having a few groups of two or three men each. The management of the shop was visibly incapable, the equipment poor, and the material, while not poor, was very poorly applied.

At the beginning of the reorganization work Mr. Spitzglass placed at the shop a very bright young man, in fact, a genius in mathematics and system, to make a systematic study of the work and to help in the reorganization of the methods and workings in the shop.

Friction arose from the first moment. The foreman openly

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objected to the various innovations introduced. The men did not like them, though they seemed to be to their advantage, and it kept him busy on one side to pacify the shop, and on the other side to hold the young man back. This went to show that the author's warnings regarding time study applied even in small shops and where the management was to be changed.

He further stated: "The author has pointed out that time study and the bonus system should be considered only after all other leaks have been attended to, that is, the leaks due to poor management in the office. In the case of office reorganization we have to deal with men who understand us at once. They are with us and helping in every way, and therefore office reorganization is comparatively easy. When it comes to time study of the men in the shop, we have to deal with individuals who are certainly not with us at the start. If they have anything against us they will not express themselves, and that keeps us working in the dark, which is the reason for waiting a sufficient time before introducing time study and the bonus system in the shop."

MARK H. LANDIS said that discussion of the question as to whether it was always right to arrange machines according to their function, led him to state an experience in his plant. On the small parts — gears, shafts, etc., and the small parts in general that were put into the stock room — it seemed better to have the machines arranged in departments, according to their functions — milling department, etc.; but for the heavy castings — beds, turrets, etc. — it seemed preferable to arrange them in departments according to the castings themselves. In his shop, about a year before, they had made a diagram showing the path that the heavy castings followed through the shop, and it amazed him to see what a tangle of lines represented the moving of the heavy castings. Such a tangle was inevitable unless the shop was so arranged that the castings followed more or less straight lines.

ELMER H. NEFF. Not the least important of the points in this paper are the ideas let in as side lights on the subject of bringing in outside temporarily employed "experts" to reform the operation of a factory. These ideas we find in Par. 5, the last sentence of Par. 13, and the latter half of Par. 18.

It has become quite a habit in this country to call in outside help with authority to upset existing shop systems and substitute others.

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Outsiders can have only a very superficial knowledge of the shop and conditions which they are attempting to reorganize. Of course, almost any one can walk through a shop and suggest offhand possible improvements. Without going into an extended discussion on that system, however, I wish to emphasize that which is so plainly in the mind of the author of this paper — namely, that the right way to reform a shop system is by putting in as its head, with proper authority, a man capable of reforming the shop methods of the organization over which he has charge.

In many factories with which I have had dealings the chief trouble has been that the man occupying the position of chief of the shop operations did not have sufficient authority and sufficient leeway so that he could actually make use in the interests of his employers of the talents for which they were paying. In that case the man himself should either compel a proper assignment of authority and duties for himself or move on to some other place.

I wish to add what emphasis I can to Par. 36 concerning the inspection department. This statement is so concise and so well fills the bill that it ought to be framed and hung in the office of every works manager, inspection department and shop-foreman's office. One of the largest machine-tool-building concerns in the world built its reputation on the quality of its product. In my judgment it owes more of that quality of product to this fundamental word that the inspection department should be responsible only to the head of the factory, than to any other one thing outside of its disposition to produce good work. In other words, this company which I have in mind might have had ever so good an equipment and ever so good workmen and management, but with this one requisite lacking and the independence of the shop inspection, it would never have got beyond the position of the ordinary shop as regards the uniform quality of its output.

ADOLPH L. DE LEEUW said that if one had a shop small enough and with a small line of product, producing only a comparatively few things, Mr. Landis's plan was perfectly possible. If, on the other hand, they were making in that shop 250, or even only 25, different things, unless the output of each of the different classes of machines was very large, such an arrangement would be impracticable, and the shop would probably be arranged so as to have the larger parts follow the same route as the smaller ones.

If one went still further and took a shop where they made not 250

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different varieties but 3000, there would be a reversion and the machines would be placed in groups.

At the plant with which he was connected there was one department that assembled the machines and there were others to furnish the parts. For example, one of the parts was so small that a dozen of them could be put into the vest pocket, yet a shop with thirty or forty machines did nothing else but make that part. And yet, even in that establishment they departed from that system again. For instance, when it came to making such sheet-steel pressed parts as afterward had to be milled or drilled, all the press work was done in the press department and the parts then thrown back into the drill department, because there the skill and knowledge required to get the best results in the presses was such an absolutely individual thing that it would not pay to have the presses distributed over the entire shop. And this system again might be reversed. Though the pressed parts should all be kept in the press shop, yet there were parts which required such particular knowledge of the function of that part after it was made, that it was better again to put the presses in the department where the part was made.

This was exactly the condition that would be found in most shops. No general rule could be of any value unless a very careful study was made of the individual requirements of that shop and of parts made in it. There were certain screws made in the screw department, but there were screws made in other departments, too, because there the important thing was to understand the requirements of a particular screw, which was of greater importance than knowing how to make the screw mechanically.

He would suggest that in discussing the arrangement of machines in the shop we forget all about any general rule which might be presented, or that ever had been presented, and study the problem as we found it.

CARL G. BARTH (written). As Mr. Kent's paper reads in the main as if it were written by someone directly trained in the art of managing by Dr. Taylor, I most heartily agree with nearly everything it contains. What he says about leaving such matters as time studies and wage-payment schemes to the last, when organizing a shop, I believe in so fully that I wish it could be made a law in our statute books; for the introduction of these features of scientific management before the proper foundation for them has been laid is doing a great deal of harm around the country, particularly as only

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too often the men entrusted with that kind of work lack the necessary knowledge and experience to do it properly at any time.

The ideal way of effecting a reorganization of a shop undoubtedly is, as Mr. Kent says, by putting a competent man at the head of the organization to do the work; but, unfortunately, there are not enough of that kind of men to go around, so that there is still a legitimate field for the professional outside reorganizer. Such a man should, however, as has now been my own practice for some ten years past, to the greatest possible extent do his work through some one in the permanent organization, whose education in modern management methods thus becomes his principal task.

In nearly all the shops that I have reorganized, the product has been of such a nature that my efforts have been to group similar machinery together; that is, adopt what may be termed the functional arrangement of the machines; but under certain conditions it would be absolutely preposterous to do this, and no hard and fast rule can be laid down in this matter. Each shop becomes properly a study of its own.

H. WADE HIBBARD said, in criticism of Par. 5, that a wage-payment scheme was not necessarily involved in time study. Certainly time study should come early, preceded by analysis of an operation into its elements, then timing the elements. Often it was found that the company was itself the greatest time waster, and this waste could be eliminated without any reference to the wage-payment system.

THE AUTHOR. The discussion seems to make it necessary to reiterate what was said at the beginning of the paper: namely, that the paper is confined to the treatment of an organization employing from 300 to 600 employees engaged in producing an average line of machinery.

A great deal of the discussion about the arrangement of machines according to classes or according to the pieces produced is very interesting, but is beside the point so far as the paper is concerned. However, it seems to me that in a shop of any size, if its product is subject to any variation at all and to alteration of design, there is a fundamental principle which makes possible a fairly general rule.

The most important factor in the grouping of machines is the need for getting the greatest skill obtainable in the organization applied to each operation. Skill of operation will far more than offset con-

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siderable expense in the transportation of material which may result from the necessity of moving pieces even of considerable weight over considerable territory. In other words, the man in an organization who knows most about screw machines should have all screw machines in his department and be responsible for all screw-machine work. The man who has made a specialty of planing and who treats it as his life work will know far more about his job and will take far greater pains in his work than any man who has charge of the manufacture of one piece requiring many different machines other than the planer, and this man whose specialty is planing should therefore have charge of all planers in the shop and be responsible for all planing work.

I have tried to show at various points in this paper, and wish again to emphasize the fact, that the most important factor to be dealt with in the shop organization is the human element. This factor is, of course, the least subject to the exact operation of formal rules. It is never long the same in any one shop and never the same in any two shops, and it is the most important thing to consider in the question of the time at which it is most advantageous to take up time study.

It is, of course, never amiss for the foreman of a department to study very carefully the efficiency of any of the operations carried on in his department, and to suggest and carry out changes, but the bringing into the department of some stranger, or a man whom the workmen look upon as a stranger, to carry on a scientific analytical study of operations, is a thing to be taken up only after all obvious leaks are stopped and the confidence of the workmen firmly established. In fact, it is my belief that reorganization can be carried on with the greatest profit where the fact of reorganization is kept very thoroughly in the background and even not suspected by the average workman. It is true that conditions may sometimes be so bad that violent action is the only possible means of introducing a remedy, but in general it is safe to say that the best types of shop organization are like the best types of life everywhere; they are a matter of growth rather than revolution.

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No. 1591

METAL PLANERS AND METHODS OF PRODUCTION

By Charles Meier, Cincinnati, Ohio
Associate of the Society

Planer Design: High-speed steel and the desire to obtain the highest possible speeds in both directions have rendered changes in planer design imperative.

One of the objections to speeding up the machine has been the difficulty encountered at the reverse. This was at first partly overcome by lightening the driving pulleys, and has been now most satisfactorily met by the reversible motor drive.

To eliminate fatigue of the operator and save time, rapid power traverse is now generally used. This is quite a departure from the standard construction, in which the heads are operated by hand.

Production: Comparatively little thought has been given to handling work on the planer. An analysis shows that the machine itself is engaged only a small part of the time required for the complete operation.

Jigs, gang tools and double-ended cutters have assisted greatly in cutting down lost time; in a case cited the proper jig cut down the total time from 28 to 4 hours.

THE problem of providing the increased speeds and power to develop the possibilities of high-speed steel and to meet the increasing necessity for greater production has been a comparatively simple one in such machines as lathes, drilling machines, boring mills, milling machines in which the cutting is continuous and the motion of the tool is in one direction only. In this type of machine it has meant merely adding power and strengthening parts.

2 The speeding-up process introduces, however, a vastly different problem in such machines as slotters, shapers and planers, in which the cutting is not continuous and which have a return motion of the tool. The principal limitations of machines of this class, especially the planer, are twofold: *first*, the inertia of the moving mass at the moment of reverse; *second*, the speed at which the tool enters the work. The problem of overcoming these limitations has had the attention of quite a number of engineers, and while considerable

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progress has been made the complete solution does not seem to have been reached.

3 The evolution of the planing machine has followed along the lines of increased table speeds. The earlier demands were all for a higher return speed, in the belief that great savings could be effected by reducing the idle time consumed in the return of the table.

4 It next followed that further gains could be made by increasing the cutting speed, owing to the fact that this part of the cycle consumes the greater part of the time involved. The advent of high-speed steel can be credited largely with the marked advance in this part of the development.

5 After fairly high speeds in both directions were obtained there came the demand for variable cutting speeds. It soon became a recognized fact that to operate a planer having only one cutting speed was both wasteful and detrimental to the best methods of increased production.

6 This constant change of conditions, and the desire to obtain the highest possible speeds in both directions, led to serious difficulties for which a change in design became imperative.

7 One of the objections to the speeding-up of the planer was the difficulty encountered at the reverse, namely, the inertia of the moving parts. Several tests were conducted which established the fact that the greater part of the trouble was caused by heavy machine pulleys and their high speeds.

8 Various types of magnetic, pneumatic and mechanically operated clutch drives were designed in which the pulleys were not reversed. Our experience with these drives was that they developed the objectionable features inherent to friction clutches, namely, the slippage and wear which takes place before the parts are properly engaged. The most successful of these types was the pneumatic clutch.

9 A few planers were built which embodied heavy springs to overcome the shock at reversing. We designed one machine in which these springs were added into the driving gears, and in another machine the table rack was made floating and held in place by two heavy springs at either end. These designs did not prove satisfactory, owing to the variable pressures while under heavy or light cutting. Also the springs had very little effect at the moment of reverse.

10 It seemed that none of these arrangements quite met all conditions, and to overcome the difficulties in the standard belt-shifting machines experiments were conducted with lighter driving

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pulleys. A step which marked quite an advance in this direction was the use of an aluminum alloy for the pulleys instead of cast iron.

TABLE 1 TEST ON 30×30×14-FT. CINCINNATI PLANER TO SHOW THE GAIN IN STROKES AND EFFICIENCY OF ALUMINUM DRIVING PULLEYS OVER CAST-IRON DRIVING PULLEYS

CUTTING SPEED 40 FT., RETURN SPEED 90 FT.

Length of stroke, ft.	Time table was running, min.	Number of cutting strokes with c.i. pulleys, weight 56 lb.	Number of cutting strokes with aluminum pulleys weight 20 lb.	Number of strokes gained	Theoretical number of strokes	Per cent efficiency of aluminum pulleys
2	30	306	350	44	415	84.3
4	30	165	189	24	207	91.3
10	30	76	82	6	83	98.7

It was found that not only did this overcome the greater part of the objections to the heavier pulleys but that higher speeds were possible,

TABLE 2 TEST OF 76×62×32-FT. CINCINNATI PLANER WITH CAST-IRON AND ALUMINUM PULLEYS

Amp. gear box and loose pulley	Amp. platen in direction of cut		Amp. platen in direction of return		Amp. reverse from cut to return		Amp. reverse from return to cut		Length of stroke, ft.	Remarks
	with c.i. pulley	with Aluminum pulley	with c.i. pulley	with aluminum pulley	with c.i. pulley	with aluminum pulley	with c.i. pulley	with aluminum pulley		
15	20	20	27½	28½	132½	106½	91½	75	0.66	Lengthening the stroke from 8 in. to 20 ft. does not alter the result 2 amperes either way
14	22½	20	30	28½	132½	105	93½	76½	20	
16	21½	21½	30	30	130	105	95	76½	20	
15	21½	20.4	30	29 1/7	132½	105	93½	76½	This line is average	
4.4	6.3	6	8.8	8.6	39	30.9	27½	22.4	Average hp.	

so that a decided gain was made in the number of cutting strokes owing to the fact that less time was consumed in the reverse. Table 1

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gives results of a test made on a 30 × 30 × 14-ft. planer and gives a good idea of the gains effected by the use of aluminum pulleys.

11 These pulleys were also found to effect quite a saving in power at the moment of reverse. Table 2 shows a test made on a 76 × 62 × 32-ft. planer, in which this saving in power was about 25 per cent.

12 The subject of individual electric-motor drive for planers has received considerable attention in the past few years. One type of drive which has been successfully developed is the variable-speed drive. This consists of a 1 to 2 variable-speed motor coupled direct to the top driving shaft of the planer. The speed of this motor is controlled by two separate sets of resistance which are automatically operated by a master switch connected to the shifting mechanism of the planer.

13 The cutting speed can be varied from 25 to 50 ft. per min., while the return speed may be varied if desired without affecting the cut. The controller handles are set to a predetermined speed before starting. The planer is operated in the usual manner from the tumbler, and the master switch automatically varies the speed of the motor at each reversal. This type of drive has the desirable feature of eliminating the mechanically operated speed variators and is quite simple in operation. It provides a very flexible arrangement when variable speeds are desired. This is especially true on the smaller sizes of planers.

14 Probably the most interesting motor application to planers in recent years is the reversible motor drive. While it cannot be claimed that the application of this type of drive is new, it can be stated that the drive approaches more nearly the ideal planer drive than any other method heretofore used. By coupling the motor direct to the first driving shaft, the entire reversing mechanism, pulleys and belts are eliminated and all the objections before enumerated are successfully overcome.

15 The motor is an adjustable-speed motor, having a speed range of 1 to 4, so that a large range of cutting speeds from 25 to 60 ft. per min. and return speeds up to 100 ft. can be obtained. A double set of resistance is provided, making it possible to vary either cutting or return speed independently of the other. This arrangement has also simplified the problem of variable speeds in connection with this drive.

16 The operating mechanism is handled in exactly the same manner as is the standard belt-shifting-type planer, so that no com-

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plications are encountered by the operator. Two predominating features in this type of drive are the total absence of belt slippage under heavy cutting and the lower peak loads at the moment of reverse. Table 3 shows the importance of these two features over the belt drive.

17 It can be said that the reversible motor drive as applied today furnishes about all that can be desired of an efficient planer drive.

18 The study of fatigue of the operator and easy control of the machine is receiving quite a lot of attention in almost every machine operation, and there is no doubt but that great possibilities in this direction exist in machine-tool construction.

TABLE 3 TEST MADE BY GENERAL ELECTRIC CO., ON 60-IN.×72-IN. PLANER

	Single belt drive	Double belt drive	Pneumatic clutch running at 200 r.p.m. on cut and 600 r.p.m. on return	Pneumati clutch run ning at 70 r.p.m. on cut and 200 r.p.m. on return	Direct-connected electric motor having cutting-speed range of more than 2 to 1 and a total speed range of 4 to 1
Drive, hp	25	25	25	25	25
Stroke, ft	8	8	8	8	8
Approximate cutting load, hp	25	25	24	26	31
Peak load reverse to return, hp	55.5	44.3	75	25	20
Peak load reverse to cut, hp	25	55	36	15	20
Time return stroke, sec	7.2	7.2	7.6	6.8	5.6
Time cut stroke, sec	20	20	19.5	16	13.4
Time of cycle, sec	27.2	27.2	27.1	22.8	19
Ft. per minute return stroke	66.6	66.6	63.2	70.5	85.7
Ft. per minute cut stroke	24	24	24.6	30	35.8
Ratio cut to return, one to	2.78	2.78	2.57	2.35	2.4

19 Power operation of heavy machine parts seems to have found a permanent place in the construction of all classes of machinery. There is an increasing demand for elimination of lost time between cuts, and this feature has also found its way into the design of planers.

20 Rapid power traverse is now being generally used in manipulating planer heads in all directions. This is quite a departure from the standard construction in which the heads are operated entirely by hand. Experience has demonstrated that the new practice eliminates a considerable amount of wasted time throughout the day, and is a decided help to the operator as it saves him from undue exertion and fatigue.

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A FEW REMARKS ON PRODUCTION

21 As a general rule comparatively little thought is given to the subject of handling work on the planer. If the same amount of time and study were devoted to providing jigs and fixtures for the planer that is given other machining operations, the saving in time would be astounding. In the majority of cases a careful analysis will show that the machine itself is engaged during only a small portion of the total time taken to complete the operation. The balance of this time is lost in setting the work, measuring for roughing cuts, fitting for finishing cuts, and changing and grinding tools.

22 In planers, as in any other machines, we depend on the operator to a large extent for the best results. Invariably the question of chucking work on a planer is left to his discretion, and he proceeds to the best of his ability with the equipment allotted him, which usually consists of an assortment of bolts, clamps and blocks instead of jigs and fixtures.

23 I have found innumerable cases in which the chucking time alone almost trebled the cutting or machining time. Adding to this the time lost in changing tools and measuring work, we find as an average that the total actual time required to complete a piece of work is from 4 to 5 times the theoretical time necessary to plane the piece, the theoretical time being based on the number of square inches to be planed and the cutting and return speed used.

24 It is not surprising to find that where time studies are conducted frequently a saving from 50 to 85 per cent in time is effected, this through the elimination of wasted chucking and measuring time.

25 In the greater number of cases a holding fixture with screw adjustments can be devised so that it is only a matter of dropping the piece into this fixture and applying the clamps, which should be part of the fixture. Hardened steel plugs can also be incorporated into the jig to indicate the various heights and angles of the piece without the use of scales or referring to a drawing. These are a great help, especially in the roughing operation. Gang tools and double-end cutters also assist greatly as they save considerable time in getting correct sizes without measuring.

26 As an example of what this jigging up has meant in one instance, Fig. 1 shows a shortwall coal-cutting-machine main frame being planed. For quite a while these frames were planed in the old-fashioned way by clamping and stopping them on the planer table. The average time required for planing with this method was

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28 hours. Since the proper jigs and fixtures have been provided, these frames are now being planed complete in 4 hours. On this jig bosses are planed on which hardened blocks are set for setting the tools.

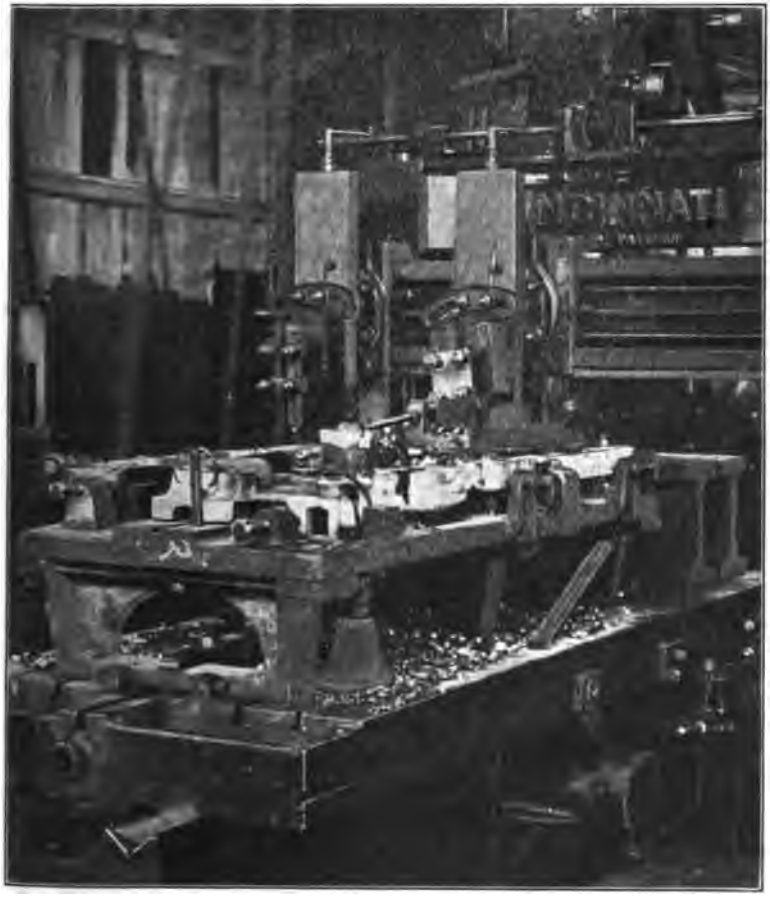

FIG. 1 EXAMPLE OF TIME-SAVING JIG ON PLANER

27 Another very good result obtained by time studies is the planing of locomotive cylinders complete in one setting. As a general rule these cylinders are planed one at a time and several settings are required. After a careful study, fixtures were provided which were so arranged that four surfaces could be planed at one time, using four

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tools for the cutting instead of only one. The saving in time on a pair of these cylinders was about 85 per cent.

28 The building of high-grade planers has established itself as an important factor in the machine-tool-building field. Many users seldom realize that, unlike smaller machine tools, the building of a planer requires a more extensive equipment of machinery, as well as a large number of costly fixtures and measuring instruments. The planer is necessarily a large and expensive machine, and proportionately larger returns are obtainable from it than from smaller machines owing to the higher expense or burden charged against it. The planer, therefore, should receive special attention from the time-study department.

DISCUSSION

CARL G. BARTH (written). Mr. Meier's paper is interesting, as it is probably the first attempt in the way of a published statement of the actual gains obtained by the use of aluminum pulleys instead of cast-iron pulleys on belt-driven and belt reversing planers, as first introduced by the Cincinnati Planer Co. However, on investigating the experimental data set forth in the tables, I find them far from consistent.

Frequently during the past seventeen years I have had to conduct similar experiments with planers of various kinds, in order to determine the length of time it takes them to make any length of double stroke between the minimum and the maximum of each one, for the purpose of incorporating this information on my Planer Time Slide Rule; and in making such experiments I work on the theory that the time consumed in stopping and reversing the planer table at the end of each stroke must be independent of the length of the stroke, and that it can hence be considered equal to the time it would take the table to travel an imaginary addition to its actual stroke at its full forward and return speeds; a theory I have again and again found to hold good near enough for all practical purposes, though it unquestionably would not for strokes as short as some I have often enough observed in poorly managed shops, in which the all-around ruinous effect of such short strokes is not recognized. Thus, if l designates the actual length of stroke and a this imaginary or ideal addition, then the total time for a double stroke will be

$$t = \frac{l+a}{v} + \frac{l+a}{V} = \frac{V+v}{vV}(l+a) = C(l+a) \quad [1]$$

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v and V being respectively the forward and return speeds of the table.

Similarly, for $l = l_1$ and $t = t_1$,

$$t_1 = C(l_1 + a) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [2]$$

and dividing [1] by [2] gives

$$a = \frac{tl_1 - t_1 l}{t_1 - t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3]$$

This shows that the experimental determination of the time for each of two double strokes only is necessary for the derivation of the value of a, and hence, if three values of t are determined experimentally, these must result in three derivations of a that must be substantially alike, if the experiments are conducted with care.

To apply this test to the data of Table 1 of the paper, we will first change it from giving the number of strokes in 30 min. to give the time for each of the three strokes. Thus:

Actual Length of Stroke, Ft.	Time in Minutes for One Double Stroke	
	Cast-iron Pulleys	Aluminum Pulleys
2	30/306 = 0.098039	30/350 = 0.085714
4	30/165 = 0.181818	30/189 = 0 158730
10	30/76 = 0.394737	30/82 = 0 365854

Considering first the times obtained for the cast-iron pulleys and substituting these in Equation [3], we get three values of a, as follows:

$$a = \frac{(0.098039 \times 10) - (0.394737 \times 2)}{0.394737 - 0.098039} = 0.6435 \text{ ft.} = 7.72 \text{ in.}$$

$$= \frac{(0.098039 \times 4) - (0.181818 \times 2)}{0.181818 - 0.098039} = 0.3404 \text{ ft.} = 4.08 \text{ in.}$$

$$= \frac{(0.181818 \times 10) - (0.394737 \times 4)}{0.394737 - 0.181818} = 1.1236 \text{ ft.} = 13.48 \text{ in.}$$

which are far from substantially alike. For the aluminum pulleys we similarly obtain for a the three unequal values 4.17 in., 5.37 in. and 7.18 in.

However, while data obtained by experiments with two different strokes are only theoretically enough for the determination of the value of a, the foregoing investigation shows the necessity of taking at least three strokes, as Mr. Meier has done, and then, in addition

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to this, of working with such care and circumspection that the three values of a independently obtained will be near enough alike for all practical purposes. My method is to plot, as in Fig. 2, the simultaneous values of l and t, with the latter obtained by means of a stop watch on which is read the time it takes for the completion of an exact number of double strokes of a carefully measured stroke.

This is far more convenient and likely to give reliable results than counting the number of strokes made in a given length of time, as by this latter method some fraction of a stroke has either to be neglected or only roughly be taken into account; and I attribute

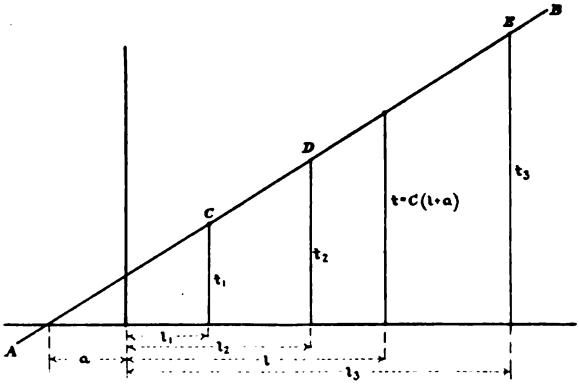

FIG. 2 METHOD OF DETERMINING VALUE OF a

Mr. Meier's failure to obtain more consistent results principally to non-success in adjusting his strokes closely enough to the 2-, 4- and 10-ft. lengths, respectively, and also to the obvious loss or overestimation of some fractional strokes, though the latter would in a 30-min. run be a very minor cause of the inconsistent data obtained.

It will readily be seen in Fig. 2 how a is graphically determined by the straight line AB drawn to pass through the three points C, D and E, when these represent a set of consistent results obtained.

After similarly plotting all of Mr. Meier's results, and taking it for granted that a only and not C in Equation [1] is affected by the substitution of aluminum pulleys for cast-iron pulleys, I have by inspection attempted to eliminate the grossest errors of Mr. Meier's observations and to write Equation [1] as

$$t = 0.0354\ (l + 1.125) \text{ for cast-iron pulleys}$$
$$t = 0.0354\ (l + 0.45) \text{ for aluminum pulleys}$$

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If I have succeeded in getting close to the truth in arriving at these equations, the value of 1.125 ft. = 13½ in. for the cast-iron pulleys as against only 0.45 ft. = 5.4 in. for the aluminum pulleys is certainly the plainest way of showing up the superiority of the latter.

Mr. Meier gives the forward speed of the planer as 40 ft. and the return speed as 90 ft., which would make the value of C in these equations = $(90 + 40)/(40 \times 90) = 0.03611$; but the plots made by me seemed to indicate that this value was too high, so the value 0.0354 was chosen. However, assuming $V/v = 90/40$, or $V = 2.25\,v$, and writing

$$C = 0.0354 = \frac{V + v}{vV} = \frac{2.25\,v + v}{2.25\,v^2}$$

gives $v = 40.8$ ft. and $V = 91.8$ ft., which are not very far from the figures given by Mr. Meier.

Let me also point out how reasonable the ratio 1.125/0.45 = 2.5 appears in comparison with the ratio of the weights of the cast-iron and aluminum pulleys, 56 lb./20 lb. = 2.8, in view of the fact that the mass alternately started and stopped is principally that of the driving pulleys of the planer, and in view of the simple laws of mechanics involved.

In Par. 11 Mr. Meier makes the unqualified statement that the aluminum pulleys also "effect quite a saving in power," and then states, by pointing to the figures in Table 2, that for a 76 × 62 × 32-ft. planer this amounted to 25 per cent, while he evidently has in mind only the maximum power expended during the period of reversal.

As the power during reversal is principally expended in overcoming the inertia of the pulleys, the total amount of this power must be more nearly proportional to the weights of the respective pulleys, while the 25 per cent of greater peak load can be explained by the well-known fact that a belt will pull the most when it slips the most, as it no doubt will when forced to stop and start the heavier cast-iron pulleys.

However, the power expended in reversing is of no consideration as compared with the wear and tear on the belts themselves and other parts of the reversing mechanism.

CHARLES FAIR (written). Mr. Meier has brought out a number of important points which should receive serious consideration. For

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a long time I have felt, as Mr. Meier does, that neither the planer manufacturer nor the planer user has given the question of handling the work or the cutting anything like the consideration it deserves. It is generally admitted, for instance, that higher cutting speeds are possible if the tool enters the work slowly and then speeds up, yet information is very meager as to how seriously this will affect the work.

On heavy roughing cuts the spring due to the increased pressure on the tool while speeding up in the work would probably be noticeable with tools not properly shaped. If only roughing cuts were required, a fine degree of accuracy would not be essential.

If roughing and finishing cuts were made, I doubt if the inaccuracies due to speeding up in the light cut would be noticeable. From such tests as I have made, this difference is not great. I have again brought up this question of speeding up in the work because, should it be required, it is very easy to accomplish with the reversing motor drives, as is also slowing down before leaving the work to prevent breaking out the metal.

Production on planers could certainly be speeded up by a more liberal use of jigs and fixtures, and in many cases double sets of jigs could be used to advantage where considerable duplicate work was being machined. This would be particularly true in cases requiring time to properly set the work.

Mr. Barth is a little hasty when he criticizes Mr. Meier's paper, largely, I should judge, on the ground of its being practical only and not consistent, presumably, with his theory. In this particular case, however, the correct theory does agree with the facts. The time of stopping and reversals varies materially with the length of stroke, as can be easily shown by tests, particularly in the case of the belt-driven planer. Further, this variation is noticeable in some cases up to a 10-ft. stroke; however, a 4- to 5-ft. stroke usually covers the noticeable variation. It will not only be necessary for Mr. Barth to substitute a variable in his equation for the different lengths of stroke, but this variable in turn will necessarily have a different value when applied to drives of the single-belt-shifting type, the rocking-idler type, the double-belt-shifting, magnetic clutch, pneumatic clutch and direct-connected reversing motor drive. These in turn will be affected by the different weights of the revolving parts, and in the case of the belt drives by the tension of the belts and by the time that it takes for one belt to get from the loose to the tight pulley and the second belt from the tight to

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the loose pulley. There are, of course, many other elements that enter into the problem, but the above are the main ones that would affect the constant a.

Mr. Barth's formula would be correct if V were a constant rate of speed instead of a variable rate of speed. An average velocity of V cannot be used to determine a. Therefore, the formula would be good only in cases where the machine had reached full speed and then only under the conditions for which the actual value of a was obtained. If a were obtained under no-load conditions it would not apply when cutting if the shifting for the reverse occurred before the tool was out of the work. The changing value of V is even more noticeable when the machine is operating under load. Fig. 2 in Mr. Barth's discussion illustrates a very simple method of obtaining a, provided the equation were one of the first degree. In reality, however, it is an equation of the second degree, which means that a would have a continually changing value depending on the changing value of V and its effect on the stopping of the platen.

If Mr. Barth's Planer Time Slide Rule is based on the formula cited, it will have to be remodeled before any claim for accuracy can be made.

THE AUTHOR. Regarding Mr. Barth's statement in his discussion that the time consumed in stopping and reversing the planer and table must be independent of the length of the stroke and can be considered equal to the time it would take the table to travel an imaginary addition to its actual stroke, I think this is where the misunderstanding comes in. I take it Mr. Barth believes a constant can be found which would be correct for all lengths of strokes. This is impossible owing to the variable quantities governing the different belt conditions; for instance, on long strokes, where the reversals are less frequent, the pulleys do not heat up and the belt slips less than it does on short strokes. It is a positive fact that if a planer is run for any length of time on short strokes (especially with cast-iron pulleys) the belt conditions are continually changing, owing to the slipping of the belts and the heating of the pulleys and the air which seems to get between the belt and the pulley. This condition becomes a great deal more aggravated on short strokes than it does on long strokes, and even at times I have seen it get to a point where the belts would smoke terribly. Any one who has stood and watched such a performance and observed the variation in the length of stroke will admit that no practical constant can be

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found which will be correct for all conditions and for all lengths of strokes.

As to the imaginary length of a perfect stroke, why try to determine on this imaginary quantity when the actual quantity can be so easily figured? Knowing the cutting and return speed and assuming there is no loss at either end, we have the actual ideal condition, which is the theoretical number of strokes I referred to in Table 1.

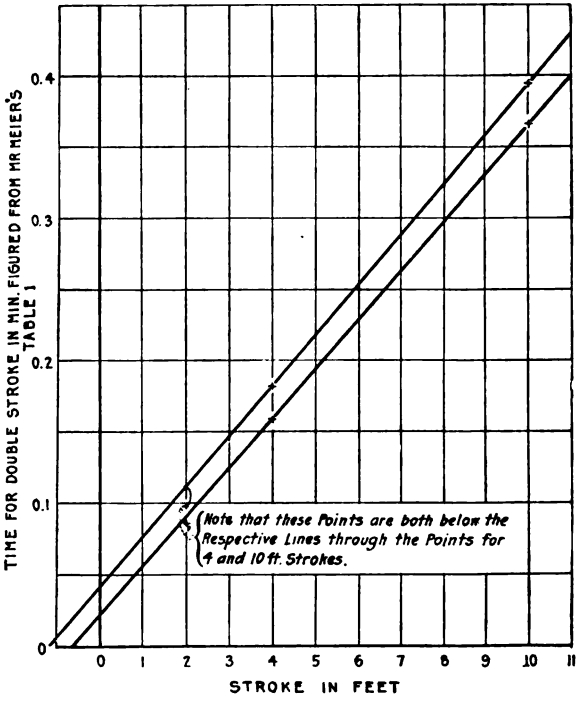

FIG. 3 PLOT OF MR. MEIER'S EXPERIMENTS

In making our aluminum pulleys we aim to get as close to this theoretical or ideal stroke as possible, and just how near we have approached this condition is represented by the efficiency column, from which it can be seen that no one constant can be found to cover all lengths of strokes which would be correct; because what would be correct for the average long strokes would not be correct for the shorter strokes. A graphical diagram such as is shown in Mr. Barth's Fig. 2 could not therefore be determined, as the values of a would be variable for different-length strokes.

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I cannot see that Mr. Barth's contentions are at all well founded, and I believe if he will carefully analyze the practical side of these points he will agree with me that I am correct in what I have said.

CARL G. BARTH.[1] I appreciate fully what Mr. Meier says in regard to the absurdity of my contention about a constant imaginary overrun for very short strokes, but as I never allow any planer to run on such absurdly short strokes, it did not occur to me to qualify my statement, as I have now done in correcting my discussion. However, I can assure him that I have too often demonstrated that my contention is correct for all practical purposes, to admit that there is any misunderstanding about this matter on my part. (For nearly eighteen years I have had a number of my planer-time slide rules in successful everyday use, and they are all based on my contentions.) Besides, the accompanying plot (Fig. 3) of his experiments clearly shows that his shortest stroke did not adversely influence the effective pull of the belt, which, in fact, indicates a higher effective pull on the shortest stroke, both for the cast-iron pulleys and the aluminum, provided any reliance can be placed on his experimental figures in Table 1. I may also say in this connection that I certainly cannot approve of Mr. Meier's way of figuring the theoretical number of strokes from the theoretical speeds 40 and 90 ft. It savors too much of time studies that give nothing closer than 0.1 min. You can arrive at such matters by indirect methods only.

Regarding the power question, in Par. 11 of his paper Mr. Meier makes the unqualified statement that the aluminum pulleys show a saving of 25 per cent in power, which, taken by itself, is very misleading, though of course he did not mean it in that way. I therefore suggest that he rewrite it something like the following:

"11 Table 2 also shows, what we should expect to find, some reduction in the peak load on the motor during reversal, namely 25 per cent, with the aluminum pulleys as against the cast-iron pulleys."

[1] Comments on the author's closure contributed to THE JOURNAL, July 1917.

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SYMPOSIUM ON MANUFACTURE OF MUNITIONS

No. 1592 *a*

MUNITIONS CONTRACTS AND THEIR FINANCING

By Frederick A. Waldron, New York, N. Y.
Member of the Society

OVER one billion dollars has been expended in the last two and one-half years on munitions, an entirely new product. Before proceeding with the discussion of financing munitions contracts, a few general statistics might serve to drive home the stupendous amount of work done on munitions by American manufacturers during this period.

2 On the basis of 30 cents per hour for labor, the number of workmen-hours would correspond to 3,500,000,000. Assuming 750 working days for two and a half years, this represents the employment of 4,444,444 workmen, which would support a population of about 20,000,000 people, or 20 per cent of the estimated population of this country.

3 There have been about 16,000,000 three-inch high-explosive and shrapnel shells manufactured in the United States during this period. The gross shipping weight was 25 lb. each, or a total weight of 400,000,000 lb., which, if shipped in carload lots of 50,000 lb. per car, would require 8000 cars or 200 freight trains of 40 cars each.

4 With this material handled ten times on an average from raw material to finished product, the car requirements would be 80,000, or 2000 trains. This would make a continuous train reaching from New York to Chicago, or 1000 miles in length.

5 A large part of these shipments have been made in less than 50,000 lb. to the car, and many shipments have been made by express,

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and it would be safe to assume that this work alone has required 1500 miles of freight cars to transport all materials.

6 If we assume a train headway of one hour, or 24 trains per day, the time required to ship this material over one trunk line in one direction would be about 900 days, or two and one-half years. With trains going in both directions at the same interval, 450 days, or one and one-fourth years, would be required.

7 This does not take into account the transportation of raw materials, explosives, clothing, arms, rifle cartridges, supplies, etc., shipped abroad.

IMPORTANCE OF FINANCING

8 The manufacture of munitions is a strictly engineering proposition in which the functions of the engineer dominate. Had engineering methods been employed in the initial stages of the work, in the past two years, instead of "corner grocery" methods of beating down in price for the sake of letting the contract at an advantageous figure, the profits in many cases would have been far in excess of what they are today.

9 Few people realize the penetration of financing into the bone and sinew of our national existence. In the daily routine of life, with the majority of people receiving a stipulated income by the day, week, month or year, the intricacies and risks involved by those providing the money to pay this income are seldom if ever thought of.

10 The forces set in motion by signing a contract, large or small, penetrate and accelerate industrial and natural resources.

11 In the last two years wonderful progress has been made in the development of resources hitherto thought to be remote or inaccessible, and the education and training of men in the allied industries have developed at a rate heretofore unknown. Why this sudden development? Why such an exhibition of human energy, both mental and physical? It was dire necessity, and necessity knew no master.

12 Money or currency is the visible medium of exchange, and if there is no money or other recognized medium of exchange, man resorts to primitive methods and fights for existence.

MAGNITUDE OF FINANCING

13 With the advent of contracts amounting to millions, few manufacturers, if any, at the beginning of the war, fully realized the time that would be required to deliver the materials. Not only this, the amounts involved were staggering. It has now become customary

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to converse in terms of millions of dollars instead of dollars and cents. Further, the difficulties of the problems, such as sub-contractors failing to perform, the increased cost and difficulty of transportation, the obtaining of tools, equipment, materials, and labor for the fulfillment of these contracts, were not anticipated.

14 With these conditions, which are now in retrospect, many industries are charging off deficits of considerable size to experience in the manufacture of munitions. Few have made fair profits. Some have made abnormal profits.

15 With the foregoing as a matter of history, the question as to how the allied nations obtained their credit would be extraneous to the subject. This brings the question before us for discussion as to how the contractor is to receive his money promptly and regularly for his work.

16 It is sufficient for the manufacturer to know that the work which he is to do will be regularly and promptly paid for, and any risks taken by him to produce in quantity within the time specified are to be amply protected by an advance of money sufficient to cover the expense of preparation.

17 Undoubtedly the cause of failures in the delivery of munitions of sufficient quantity within the time specified, is directly traceable to the lack of judgment in the amount of money demanded as advance payment, combined with a lack of business and financial management.

18 If we review carefully the ratio of the amounts advanced to the total amount of the contract and its time of completion, it will be found that in no case has a sufficient advance been made to enable the contractor to finance this work on the same basis as he would adopt in the conduct of his regular business.

WHAT IS FINANCING?

19 Financing is providing the coin of the realm in adequate and opportune quantities for the purpose of obtaining an object desired. Where ready cash is not available, the usual way of providing the coin of the realm is by the issue of mortgages, bonds or notes, which are papers promising to pay at maturity the amounts advanced, with interest of course for the use of the money, payable at specified periods during the time for which the loan is made.

20 All mortgages, bonds or notes must have tangible and preferential security, rights, etc. These principles cover the salient points

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necessary for a government, corporation or individual to obtain the necessary amount of money to pay for the object to be obtained.

21 Documents given by the party wishing to obtain the object (called the Owner or Purchaser) to the party who is to provide the object (called the Contractor or Vendor) are in the form of leases, contracts, or purchase orders, supplemented by specifications and drawings, or samples of the object desired.

22 Prior to the signing and exchange of these documents, the money which the purchaser wishes to use to attain his object has been provided. Upon the signing and exchange of these documents, the details are planned for distributing this money in adequate and opportune quantities in order that the object to be attained may be completed as rapidly as possible and the contractor provided with sufficient funds to promptly and efficiently complete his work.

23 If a purchase order or contract exceeds a certain amount and covers a definite period of time, a bond is required in order to protect the purchaser.

24 On large munitions contracts, the bonds of sub-contractors are marshalled by the general contractor and deposited as security. This is to indemnify the purchaser against loss. In fact, the bond is the purchaser's insurance to secure him against failure to complete the work or the dissipation of moneys paid by the purchaser to the contractor as an advance payment. A bond is also required by those financing the work.

ADVANCE PAYMENTS

1 When and how met
2 Amount in percentage of the total amount of the contract
3 Rate of liquidation
4 Interest charges.

PAYMENTS ON ACCOUNT

1 When to be met. Depends on:
   a Resources of contractor
   b Volume and rate of delivery of material
   c General progress of work
   d Complete information.
2 Amount of payments:
   a Purchase value less a certain percentage for reserve or adjustment at end of contract
   b A purchase value or agreed amount to liquidate advanced payments.

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3 Types of payments:
a Sight draft, check, notes or bonds.

FINAL PAYMENTS AND ADJUSTMENTS

1 Adjustment of percentage held back on part payments
2 Adjustment of debits and credits during the progress of the contract
3 Types of funds:
a Notes, bonds, sight drafts, checks.

DISCUSSION OF ADVANCE PAYMENTS

25 In manufacturing and contracting requirements it is a well-known fact that from three to five turnovers of inventory per year are essential to a reasonable profit.

26 Large contracts have been let on the basis of a ten-months' delivery in which the advance exacted was 14 per cent, and this in the face of the fact that the work was entirely new, the detailed requirements unknown, and nothing of the magnitude had ever been undertaken in this country prior to March 1915.

27 The general contractor, on a large munitions contract, has to provide in turn advances not only to the sub-contractor but he must also be able to take advantage of the market, and oftentimes buy materials long before they are required. He has also to meet the payments for materials of sub-contractors furnished long in advance of the time they are to be used. Then, again, contracts have been let to some small concerns which have failed to fulfill the requirements of the contract. This also applies to the larger sub-contractors and, as has been the case, it is necessary for the general contractor, in order to protect himself, to take control of the entire properties of the sub-contractor on an entirely different basis and under entirely different conditions. This involves delays not ordinarily estimated in the contemplation of the work to be done.

28 A further necessity for ample and proper financing during the progress of the contract, is that assembling contractors be supplied with a sufficient number of component parts of proper quality in order to complete the work.

29 It is quite possible (in fact, it has happened) that manufacturers of component parts have held up shipments awaiting payments on their materials. To my knowledge this has involved at different times delays in the completion of work valued at from one to three million dollars over a period of time of from two to five weeks,

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which, if figured on the basis of six per cent, would mean a loss to the general contractor of from $4000 to $12,000 in interest charges alone.

30 But, beyond all of this is the demoralizing effect on a subcontractor and the discouragement which he experiences. This reacts upon the organization, and in a very short time the enthusiasm and efficiency of the personnel of the plant have rapidly deteriorated.

31 Then, again, the question of financing depends to a large extent upon the government with which the general contractor is dealing. With some there is no trouble, and businesslike methods are used in the handling of all financial transactions. There are others, however, that are exceedingly troublesome and irregular in meeting their financial obligations and, while they are good for the money obligated, the irregularity and slowness of payments oftentimes creates suspicion and distrust on the part of the manufacturer, with a corresponding demoralization.

32 After an observation and experience of two years in this work, the writer feels safe in assuming that an advance of at least 25 per cent is necessary and 33⅓ per cent would leave a margin of safety, with good management.

33 It is not necessary that all of this amount be paid upon the signing of the contract, but it should be available for use should occasion require.

34 The rate at which advance payments should be liquidated is a matter which can only be adjusted to the requirements of the case in hand. A good rule to follow is to deduct from each invoice the same percentage of this invoice as would liquidate the advance payment upon the completion of the contract. It is customary, in some contracts, to deduct an additional ten per cent as an adjustment fund to protect the purchaser at the completion of the contract.

35 Interest charges are sometimes demanded on advance payments, but the usual practice is to dispense with this charge.

PAYMENTS ON ACCOUNT

36 Payments on account depend on the resources of the contractor, volume of business, rate and quality of materials delivered, general progress of the work, and complete audit information as to the financial condition of the contractor.

37 The amounts of these payments are generally made on the invoice value of the materials shipped, less deductions for the liquidations of the advance payments and insurance to the purchaser.

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38 The types of payments usually made are either cash on receipt of the bill of lading or sight draft; or settlements at certain defined periods, either by the week, semi-monthly or monthly; sometimes, thirty days from the receipt of the invoice, bills of lading or inspectors' certificates.

39 Where the financial standing of the company is such as enables it to have cash on hand or available to conduct its business, payments are taken in bonds or short-term notes of the government for which the work is being done.

FINAL PAYMENTS

40 Final payments should be made as promptly as possible upon the completion of the contract. It is hardly possible, in the majority of contracts, to make these final payments promptly, as it oftentimes involves the adjustment of debits and credits for expenses on the part of the contractor and rejected work or spoiled materials on account of the purchaser. It is essential, therefore, in order to have a prompt adjustment, that a close check be kept on the progress of the work at all stages and a clear and definite method of maintaining records be kept by both purchaser and contractor.

41 The types of funds used in final payments are the same as these used for payments on account.

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No. 1592*b*

ORGANIZING FOR MUNITIONS MANUFACTURE

By Arthur L. Humphrey, Wilmerding, Pa.
Member of the Society

THE task of organizing a plant to undertake the manufacture of munitions is one of many factors. In fact, organizing involves all of the items in the general list: specifications, materials, designing, limits, gages, inspecting, etc. The general success of the undertaking is dependent upon the perfection of the working organization, upon the selection and installation of adequate machines and other tools, and upon the careful planning of the work, which is not limited to that within the shop alone but involves a consideration of the market, the purchase and delivery of supplies.

2 The financing accomplished, the task of organizing comes next in order. Their work done, the financial backers of the undertaking become impatient to see deliveries made because of their failure to understand the mechanical and human problems in the task of organizing, and a net loss is the result of insufficient time being allowed for perfecting the working organization, equipping for and planning the work. Haste makes waste in most affairs and it is not the exception here. A premature beginning may result in an encounter with conditions which will mean an entire revamping of the whole scheme — conditions which would have been determined and provided for had sufficient time been given for careful planning and making schedules complete in every detail from start to finish.

3 It is quite essential that an organization for the manufacture of munitions be built around a nucleus of men who have had experience either in munition making or in work of an allied character. With such a group as a basis it is comparatively easy to place new men and ramify the organization into the various departments and divisions, each properly correlated with the other. It should be so

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arranged that each department acts as a unit within itself and attends to but one thing, such, for instance, as manufacturing the shrapnel time fuse and that alone.

4 Many operations in the manufacture of munitions can not only be as well done by women as by men but are better done by female help. These operations are such as involve light delicate work requiring deftness and dexterity in the use of the fingers. Therefore such work should be segregated at every opportunity and the organization be made to include the requisite number of women.

5 The work to be accomplished is first revealed by the specifications submitted. Conferences between the engineers and shop foremen should be held at frequent intervals as the planning and scheduling progresses in accordance with the results demanded by the specications, and the whole problem should in this way be thoroughly "threshed over."

6 This problem of organizing is closely bound up with that of equipment. The condition of the machinery market and the urgency of the contract will determine largely the type of machines installed. In every case, where possible, automatic or semi-automatic machines should be given preference in order to get maximum accuracy with a minimum skill requirement on the part of the operators. This reduces materially the losses due to error of the individual. Careful consideration should be given to every detail of the manufacture, a thorough time study made, and the most logical sequence of operations worked up and scheduled before decisions are made as to the types of machines to be installed. Too much stress cannot be placed upon this feature, for any changes it may be necessary to effect after the machines have been ordered will result either in considerable loss or inefficient manufacture. Grouping of the machines should also be gone into very carefully to avoid unnecessary handling between successive operations.

7 Great emphasis must be placed on the necessity for a well-organized and well-equipped tool room. It is of paramount importance to have an unstinted supply of gages, jigs, machine fixtures and other special tools, for these are needed in great number in the manufacture of munitions. They are, in fact, indispensable to the successful quantity production of accurate work.

8 Also, upon the inspection department will depend the proper utilization of the gages supplied by the tool room — in other words, the inspection department and the tool room are links in the same highly important chain of accuracy. A carefully organized inspection

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force must check the product not only at the end but at each successive stage of manufacture. The product must be checked not only for variations in dimensions but for chemical and physical properties as well. The personnel of the inspection force is of the utmost importance, for it is quite unwise to give the power of rejection to a group of uninformed inspectors who are lacking in judgment. And if power to reject be withheld the inspection force might well be entirely dispensed with.

9 Other points of interest in this general connection may be found in the writer's paper on The Mobilization of Material and Industrial Resources, read before the Engineers' Society of Western Pennsylvania on May 31, 1916.

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No. 1592 *c*

ORGANIZATION FOR MUNITIONS MANUFACTURE

By Harry L. Coe, Boston, Mass.
Member of the Society

THE field of this paper is limited to a study of the organization found effective in plants turning out projectiles particularly of the smaller types. I have approached this subject from the viewpoint of a manufacturer already engaged in a metal-working business, and have tried to suggest some of the factors which he should consider if he expects to produce projectiles. Assuming that the manufacturer has ample financial resources, adequate equipment, a satisfactory source of raw materials, etc., what type of an organization is essential to the successful production of munitions; and among the various kinds of munitions, what articles can the particular plant produce economically?

2 Much time and effort will be wasted if this double process of selection is not given attention. The characteristic optimism and confidence of the American manufacturer, coupled with the strong desire to be of service to his country, or to make money, lead many firms into making persistent efforts to get munitions contracts which should, logically, go to firms of an entirely different character and facilities.

3 Before looking for a munition contract, there should be an honest self-analysis to clearly define the fundamental qualities on which the success of the existing organization is based. It isn't a question of "can my shop produce this piece?" but "can it make this piece as well and as economically as anyone else?"

4 Many firms having a good manufacturing organization will feel that they require only a little additional equipment. To these people I say, "Beware!" Three years ago they might have had as good a chance of success as any one, but today they will have to com-

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pete with the firms which have not only the organization but the proper equipment as well.

5 On the other hand, they may have a general equipment which can be adapted to munitions, but their shop and executive organization may not be trained to think and act along the lines of specialized mass production. And here again I say, "Beware!" Difficult, slow, and expensive though it may seem to start from nothing and equip a complete munitions plant, it is much more difficult, slow, and expensive to develop and get into effective operation the organization which will make this kind of a business successful.

HABIT AND TRADITION LACKING IN MUNITIONS MANUFACTURE

6 We turn with pride to our great industries — the steel corporation, our railroads, etc. — and feel that certainly the American genius and ability which has made them possible can turn out unlimited quantities of shells. And so they can, *if they have time.* Unfortunately for the manufacturer, this element of time is of the greatest importance to the fighting units. The advantage lies with the side which first gets the necessary supplies.

7 The big, centralized organizations are the result of a slow process of evolution and while their working force may be constantly changing, one finds that the habits and traditions of the work are maintained, and it is this force — habit and tradition — which is entirely lacking in the munitions business. To produce shells economically, this force must be generated in and by the organization, which means embodying in that organization a certain proportion of picked men, chosen because they possess these habits, or who, because of their versatility and training, can quickly acquire them. Such men are not easy to find, and the time it would take to get *enough* of them together in one place to make a large organization successful is almost a fatal handicap.

8 It would seem, therefore, that the greatest success would be obtained by comparatively small units specializing in one type of munitions. One may say, "Why not have a big shop departmentalized, with a case shop here, a shell shop there, time fuses or primers in another section, etc.?" Theoretically, this would be all right, but if one studies the organizations which have tried this in the past few years, he will find a tremendous amount of lost time, effort, and money. In other industries where this principle has been successfully developed, I believe there will be found quite a percentage of

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men in each division who have grown gray-haired with years of service along that particular line.

9 This condition does not obtain today with respect to the munitions business. Before the present year the firms manufacturing projectiles in the United States were very few, and there is a very limited field from which to draw either workmen or executives "skilled in the art." The orders placed by our Government outside of its own arsenals were so small that even at the high figures paid they offered no attractions to anyone to develop a business along these lines. As a rule, the training in the arsenals has not fitted men to produce the best results under our existing industrial conditions, and at the present time the arsenals are not letting any of their good men get away. In general, the attitude of the War Department has not encouraged the development of this industry except in the case of a few manufacturers as mentioned above. The result is that there is a very limited field from which to draw either workmen or executives with experience in this kind of work.

10 It would seem, therefore, that the manufacturer must build an organization around such of his men as possess the proper habits and training, and they in turn will have to see to the development of the manufacturing units. Here, again, large and complicated units do not develop rapidly and in them mistakes are tremendously expensive and slow to correct.

11 The manufacturer should therefore take stock of his organization carefully. If it does not contain men whose habits of thought and training are consistent with specialization of processes and mass production, it lacks one of the prime factors in successful munition manufacture.

ADAPTABILITY OF PLANT TO PRODUCT

12 If, on the other hand, the organization *is* of this type, he should look carefully over the wide range of articles classified as munitions and select something which is as similar as possible to his regular product in size, material, and general nature.

13 We hear of gray-iron foundries making strenuous efforts to get contracts for producing cartridge cases, when the nearest thing they have to a press is a plate-molding machine, and they never had an opportunity of running to capacity on a single pattern for more than a few days at a time. Needless to say, if such people are so unfortunate as to get a contract, it is almost certain to prove an expensive failure for them and may result in a serious shortage of supplies for the fighting line.

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DEVELOPMENT OF THE ORGANIZATION

14 Assuming now that there is an organization which is accustomed to specialization and that a type of munitions adapted to the available equipment has been selected, what subdivision should be made in the organization and what functions should be performed by each?

15 In the first place, it is futile to try to handle a projectile department as an appendage to some other part of the business. It is a business in itself and its success or failure will probably depend on the completeness with which every detail is worked out and checked.

16 This is a product in which duplication inside exceedingly small limits is essential. Moreover, if one agrees with the theory of specialization mentioned above, the type of munitions manufactured will be limited to a few pieces, or even to a single piece, of the same nature. The size of the order should be large enough so that even the smallest working unit — man or machine — can be employed constantly on the same operation. Under such conditions no detail is so small but that it pays to give it careful attention. Every motion will be repeated many times an hour and the expense due to trivial losses will soon reach large proportions. Realizing this and knowing that this is a temporary business, many firms have gone outside of their regular force and employed special managers to look after their projectile manufacture. This has been their sole function and the arrangement was terminated when the order was completed.

17 The internal mechanism of the organization, then, might be classified somewhat as follows:

I General Service Department
II Diplomatic Staff
III Production Department
IV Inspection Department.

I GENERAL SERVICE DEPARTMENT

18 Under the General Service Department we find

a Records and accounting (with special prominence given to control of manufacture rather than to details of cost-finding)
b Purchasing and stores organization
c Designing, drafting and experimental development
d Protection and safety (with special reference to destruction by representatives of the enemy's government and to the safeguarding of unskilled workers).

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19 With reference to these general departments, it may be safe to modify our general principle of entirely separate organizations. Whether or not these departments are combined with the existing departments employed in similar work will depend somewhat on the volume of the work both in the normal business and in the munition contract, as well as on the physical layout of the plant. In most cases it is possible so to plan that this work will follow the practice developed for the regular business and can be absorbed by the departments already doing this kind of work.

20 With reference to the purchase and stores of the department there are no special features which differ to any radical degree from ordinary practice.

II Diplomatic Staff

21 While this organization will be small, it is none the less important. If the munitions are for a foreign government, there will undoubtedly be foreign representatives stationed at the plant as receivers. These men are not accustomed to our methods. Their temperament is entirely different from the people we are ordinarily meeting. Possibly they do not speak our language. If sufficient attention is given to them and their points of contact with the organization are limited as far as possible to a few chosen men, it will be much easier to reach a practical working basis and to prevent expensive and often unnecessary misunderstandings and delays.

22 This department is responsible for seeing that these receivers are provided with the information they desire and that it is presented to them in such a way that they get a correct impression of the conditions. If they appreciate the difficulties which may be arising and the action the organization is taking to eliminate causes of trouble, it naturally affects their attitude toward the plant.

23 The diplomatic staff sees to it that any instructions issued by the receivers are transmitted to the proper department so that they go into effect.

24 Through this department the shop can approach the receivers for information or rulings on conditions which may not be clear.

25 Even in the cases of work for our own Government, I believe such a department is advisable. The fewer people who have official relations with these receivers, the less the chance of contradictory instructions or of false or unnecessary information or misunderstandings.

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III Production Department

26 Under the Production Department come

a Maintenance of equipment
b Operation of equipment
c Selection and training of workmen
d Tool and gage production
e Establishment and operation of wage-payment and penalties systems.

This department is responsible for maintaining production and developing economy, and has full control of all agencies which bear directly on the operation of equipment.

27 Maintenance of equipment has been included under this department for two reasons. First, it brings the time element of repairs largely under its control. Much loss of production can be avoided by a careful and frequent inspection of machines and transmission. A few hours in adjusting may save days of shutdown later. And, second, because the men who make up the maintenance crew are usually the general group of millwrights who see to the location and moving of equipment, which again is a direct corollary of production. When breakdowns occur, operations have to be readjusted, and it is often more economical to take an idle machine out of a battery and replace with a spare than to interrupt the flow of product. Such work is obviously up to the repair gang.

28 In this connection I am inclined to think that twenty hours per day is about the economical limit to run machines under the conditions of forced production usual on this work. The extra four hours for repairs is most excellent insurance.

29 Because of vital relation to production the tool and gage manufacturing department is made a part of the production chief's organization. I say tool and gage *manufacturing* department instead of tool room advisedly, for it has to be a real manufacturing department with the demand for flat cutters, boring bars and heavy supplies of special tools which immediately occurs when one starts to reach maximum output on single-operation machines.

30 It is often possible to put through really good-sized manufacturing orders for individual special tools, such as flat cutters, etc., and even establish bonus or piece rates for their production. Because of the quantity needed and possibility of standardization on such work, it is inconsistent with the ordinary tool-room atmosphere

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and habits of work. The good tool maker is not as a rule a production man and it is a difficult thing to get a tool room into the spirit of manufacturing. This is not so true, however, of the gage and tool-designing department, which has been placed under (*c*) of the General Service Department.

TRAINING MACHINE OPERATORS

31 Having given the production chief the means of supplying his working force with equipment to use, we turn to a study of the workers.

32 Because of the difficulty of getting skilled mechanics, it has been necessary to develop that type of an organization which can produce results with the average workman in the shortest possible time. This is one of the reasons why it is well to subdivide the operations into simple elements and eliminate complex machines. Because of the very nature of the class of workmen available, it is necessary to make the most out of a continually changing force. This has been done successfully by selecting from the better grade of men a class which might be called *tool setters* or *machine starters*, and giving them charge of a battery of machines. It is their duty to teach the workman all he is capable of learning and to see that any conditions resulting in loss of quality or production from the direct operation of the machines, due to the operator or tools, are remedied. This builds up a secondary line of defence, as it were, and it is possible to develop a fairly permanent organization of this kind of men. Behind these machine starters come the group foremen, assistant superintendents, etc.

33 The method of wage payment for all these men is immaterial provided a maximum incentive is given to each man. Personally, I am in favor of a thorough piece-work system as it is simple for the workman to understand and not expensive to operate. However, premium or bonus plans are all right if the rewards are immediate. The setting of standards is an important part of the wage basis and the opportunities for the competent operation and time-study man are wonderful. He, too, is part of the production chief's organization.

34 In this connection, while in general the theory of penalties is not desirable, it has been found that it is a good balance wheel to the continuous insistence put on production, especially where the workmen are not trained in the true spirit of machine-shop existence and often are only transients with very little interest in the quality of their work.

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IV Inspection Department

35 The work of the Inspection Department comprises

a Inspection of operations
b Intermediate inspection
c Final inspection.

36 To some it may seem that at least part of the inspection organization should be directly under the chief of production: for example, the first or operation inspection which occurs after each operation. I believe, however, that better results and a more consistent and thorough inspection will ensue by creating a staff of inspectors responsible to their own chief to handle all inspections wherever they occur. It is easier to train men for these jobs and instil into them the necessary standards of work and habits of thought and action if they are included in a branch of the organization which is all their own.

37 Assuming that the complete inspection is organized into a department of its own, it may well develop according to the following scheme:

38 If the work has been subdivided so that operations occurring on individual machines are simple, it is possible to station back of each group of machines an inspector or inspectors and gage every piece for the controlling dimensions. We might class these inspectors as *operation inspectors*. It is their duty to see that each piece produced falls inside the tolerances which are allowed.

39 These inspectors should keep a record of the output of each man, which is the basis of his wages. In addition to keeping a tally of the good pieces produced, they also classify their rejects, charging them to the operator who is responsible for the errors. The study of these inspection records, as may be readily seen, is a very valuable guide to the production superintendent in remedying processes or conditions which are producing scrap. They also make an excellent basis for an efficiency rating of the operators and machine starters.

40 As the work progresses and a series of operations are performed upon a piece, it is often found desirable to have an *intermediate inspection*, as in many cases the later operations materially change the form of the piece so that it is impossible to check the work previously done. It is usually found desirable to set aside a certain part of the shop for this purpose and have all the product delivered

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to the inspection room. All the rejects from the operation inspectors are grouped according to defects and are passed upon by the chief of the intermediate inspection. Often additional limits can be allowed in the intermediate inspection room over those permitted on the floor, and in this way many pieces which may not pass the operation inspectors can be put back into process from the intermediate inspection room. All the product which is not classed as "rejects" from the floor is considered to have passed the floor gages. The intermediate-inspection department checks enough of these dimensions to get an accurate idea of the quality of the work which the floor inspectors are doing and to see that the standards set are maintained.

41 This intermediate inspection is a general overall check on the production reported by the operation inspectors. The advantages are obvious when considered from the payroll point of view.

42 When a piece is finally finished and ready for presentation to the receivers, either of our own government or of a foreign government, there should be organized a thorough *final* inspection. Under this final inspection all dimensions possible are checked, and in general the same procedure as may be instituted by the receivers is followed out. In case the product does not come up to the standard, it is either sent back for repairs or else set aside and presented as a special batch with full explanations to the receivers. In this way the shop establishes a very desirable basis of fair play with the receivers and, as a usual thing, the policy results in the granting of special limits to cover slight deviations from specifications, which, if sent through with the other work, might arouse suspicion and work to the detriment of the shop.

43 In connection with the inspection organization, it is very necessary that an ample gage-checking force be organized. All working gages should be checked at least once a day and, in case of some of the finer types of gages, it may be necessary to check oftener if the standards are very exacting.

44 In conclusion, I might say that from the experience of the past few years it is evident that the smaller manufacturing organizations specializing in one class of product will reach maximum production and a high state of efficiency much more quickly than the large organization working on a variety of articles. In such an organization the element of habit and training is a more important factor than the type of work done or the equipment on which it is done. Because of the limited time which is usually available

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for munition work, it is necessary that certain fundamental characteristics should exist in the organization; that in such an organization the divisions of preparation, production and inspection should be treated as separate units, and, in general, that, due to the lack of skilled workmen, the full force of the management should be turned toward as complete and thorough a system of teaching and training as is possible from bottom to top.

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No. 1592*d*

PROCURING SPECIAL MACHINES FOR MUNITIONS MANUFACTURE

By H. V. Haight, Sherbrooke, Quebec
Member of the Society

IN asking for an introductory paper on the subject of the manufacture of munitions the Committee on Meetings suggested that the writer might "analyze the different types of machines required and indicate whether it is better to buy them or to make them."

2 As no two manufacturers of munitions follow the same methods or use the same machines, any opinions the writer may advance must be based on his own experience or observation and will be subject to confirmation or modification when compared with the experience of others. A few words as to the basis of the writer's experience will, therefore, be in order.

3 The firm with which the writer is engaged is machining and assembling the 18-lb. British shrapnel and the British 8-in. howitzer shell. Under the plan of organization of the Canadian Imperial Munitions Board, the work is all sublet by the board. The contractor for machining and assembling shrapnel, for example, is furnished with forgings for the bodies, with finished component parts such as disks, sockets, copper bands, tubes, tin cups, bullets, etc., and with the other materials required such as resin, solder, paint and shipping boxes. The following notes, therefore, cover only the machining and assembling of the above two sizes of shells, which will be taken up separately. In addition to the experience mentioned, the writer has visited many shell shops both in Canada and the United States.

EIGHTEEN-POUND SHRAPNEL

4 When undertaking the first contract for shrapnel our firm had a machine shop which could be converted to shrapnel production

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and an experienced working force. As shrapnel production increased and as the regular work picked up, additional machines were purchased or made, until all the regular tools had been withdrawn from shrapnel production. In many cases these regular machines were withdrawn because required for producing the regular product; but there was the additional reason that for four-fifths of the operations the new tools purchased or made were more productive than the regular tools used at first. Our experience, therefore, has covered the use

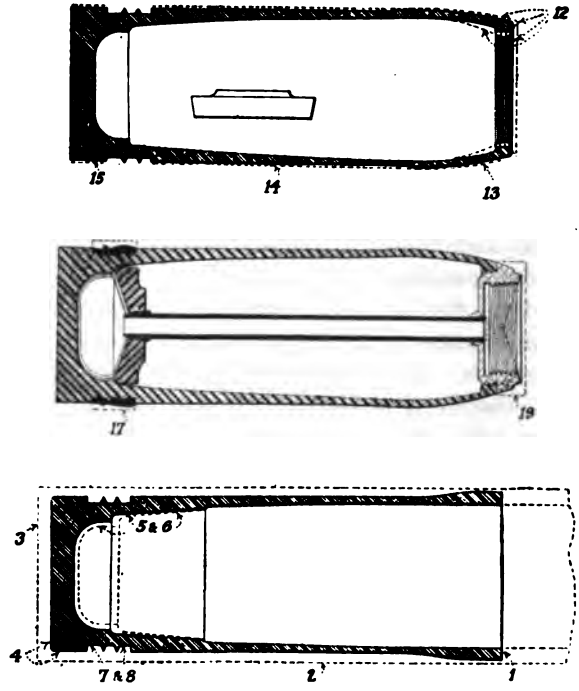

FIG. 1 INDEX OF OPERATIONS IN MACHINING SHELL

of standard machine tools, special purchased machines and special machines made by ourselves.

5 The following notes relate to the principal operations on the shrapnel and the machines which our experience shows were the best to use. Fig. 1 shows the shell at several stages and the numbers indicate the operations described below.

1 *Cut off open end.* Standard 4-in. cutting-off machines with air expanding mandrels. Production, 900 in 8

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hours. We also tried a special machine to cut off both ends at one setting and another machine of the type of a pipe-threading machine, but both proved failures and were returned to the makers. On the regular machines the air mandrel is preferred to the universal chuck as it is much quicker and costs less to keep in repair.

2 *Rough-turn body.* We used at first heavy 24-in. engine lathes, 24-in. Gisholts, Lo-swing lathes, etc., with fair results, but we are now using single-purpose lathes of our own make which produce more work and are much simpler to keep in repair. These lathes have cast-iron spindles, 6½ in. in diameter in the front bearing, with driving gear integral with the spindle. They have tight and loose pulleys on the back-gear shaft, thus eliminating countershafts with their troubles. The feed is by belt, eliminating feed-gear troubles. The work is chucked on an air expanding mandrel and turned with a bar cam to give the necessary enlargement at the open end of the shell for the subsequent bottling.

3 *Rough-face base.* We have used 36-in. engine lathes, 42-in. and 60-in. vertical boring mills, 36-in. planers, 30-in. planer-type millers, etc., on this work, but have abandoned them all for 4-in. standard cutting-off machines. On milling machines the tool upkeep is too great, on planers the work is hard to hold, on planers and boring mills the intermittent cut is hard on the machines, and on all except the cutting-off machines the labor cost and upkeep are too high. On the cutting-off machines the regular universal chuck is omitted and a plain hinged chuck used, as a universal chuck will not stand shell work. The regular cutting-off-tool blocks are replaced with a tool block to hold a facing tool. When the countershaft clutch pulleys give out, they are replaced with tight and loose pulleys. Each man runs two of these machines.

4 *Finish-face and turn base.* Standard 16-in. lathes, with air collet chucks supported by steady rests, give satisfactory service on this operation. Only hand feeds are used.

5 and 6 *Rough and finish bore.* It has been found best to rough bore on one machine and finish on another. Turrets are not desirable on shell work, where they can be easily avoided. We used a well-known make of turret

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lathes on this work, but they proved pretty light and required considerable repair. They were eventually withdrawn for regular work and replaced by special boring lathes of our own make, in which the work is held inside the spindle by an air collet chuck. Two different feed mechanisms are in successful use, one a central rack with power feed and air return, the other a crank and "Scotch Yoke" with hand feed. Another Canadian munitions plant made very successful boring machines from gasoline-engine patterns. We built a double-spindle lathe for this work but it proved a failure.

7 *Rough band groove.* This work is being done on cutting-off machines and also on lathes of our own make. In both cases the work is held in push-out air collet chucks. No longitudinal feed is required and only a hand cross-feed.

8 *Finish band groove.* This consists of undercutting the edges and forming the waved ribs. Potter and Johnston automatics are in successful use and stand up well. It has been found, however, that a man can do more work on one machine than he can on two or three, so the automatic feature is of no use on this work. Regular 20-in. engine lathes with special fixtures, and simple lathes of our own make with similar special fixtures, are now preferred as they produce rather more work. This is the only operation on which universal chucks are still used, but they will probably be superseded by air chucks. Two different purchased waving machines, built for this purpose alone, were tried but proved unsuccessful.

9 *Harden.* We used at first muffle furnaces, with cast-iron pot muffles holding eight shells, but now we use large semi-muffle furnaces holding 50 shells. The furnaces are built to designs furnished us by another shell manufacturer, but appear to be copied from a commercial furnace. We used pyrometers at first, but now the operators go by the color. An "Irite" pyrometer is used to train new men.

10 *Bottle.* The noses of the shells used to be heated by dipping in a pot of lead. This was rather expensive in the use of lead, and also gave a little trouble from lead poisoning. The present method is to heat in an oil

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furnace having holes through which the shells project into the furnace. A water-jacketed front was tried, but firebrick with iron thimbles has been found better. We built these furnaces after the style used in another shell shop. The bottling presses used at first were air presses which we made ourselves from drill sharpeners, but the present practice is to use geared crank presses which are purchased. After bottling, the shell is put back in a similar furnace to anneal the nose.

11 *Shot blast.* The regular foundry sand blast was used at first, but present practice is to use a small shot-blast machine of our own make. This has two jets, one of which cleans the band groove and the other the base. The shot blast gives practically no dust, and can be used anywhere in the shop.

12 *Turn and thread nose.* This requires a fairly heavy turret lathe, and we are using both 24-in. engine lathes and also single-purpose lathes of our own make, both of which are equipped with turrets. We prefer the latter lathes as they take the work inside the spindle and eliminate the steady rest. Air collet chucks are used. This is the only operation on the shrapnel where a turret is used and this requires five holes of the turret.

13 *Grind nose and* (14) *grind body.* Standard grinders, slightly modified for the wide wheels used on shell work, give satisfactory results, as do also special purchased shell grinders. The grinding-machine manufacturers, of all the regular machine-tool builders, come out with the greatest credit from the viewpoint of shell production. In most other cases the shell manufacturers themselves have built more suitable machines than either standard or special machines built by the machine-tool manufacturers.

15 *Grind base.* Simple machines of our own make give good results.

16 *Press copper band.* Two different hydraulic band presses, both designed and built by other shell manufacturers, are giving good results on this work.

17 *Turn band.* A heavy engine lathe with special equipment and an air collet chuck gives good results, but costs more

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money than a very good special band-turning lathe, built by another shell manufacturer.

18 *Fill.* This is nearly all home-made equipment and hardly requires detailed description here.

19 *Turn socket.* A 16-in. engine lathe is heavy enough for this. A clutch on the back gear is convenient. A turret is not desirable.

20 *Paint.* We use with satisfaction a small portable machine of our own make, driven by a $\frac{1}{8}$-hp. motor.

6 The foregoing does not cover the use of purchased single-purpose lathes, of which there are now a large number of designs on the market, but from experience with three or four types of these on 8-in. shells, it appears that they should give good results on shrapnel work. The features they should have would be a large spindle, 4 in. to 5 in. diameter, with hole at least $1\frac{5}{8}$ in., strong drive and feed, a good feed-engaging clutch, or, better still, a drop worm. The countershaft should have tight and loose pulleys, though the use of air chucks will largely eliminate countershaft troubles, as it is not necessary to stop to change the work. It is better, however, to have tight and loose pulleys on the headstock and eliminate the countershafts, as they take up so much room overhead that it is difficult to group the machines to best advantage. The elimination of countershafts also reduces the cost of belting, which is quite an item. A special point for consideration is the depth of dovetail on the carriage, for the cross-slide. This should be $1\frac{1}{8}$ in. to $1\frac{1}{4}$ in. deep, but there are at least two of these lathes on the market with dovetail $\frac{3}{8}$ in. to $\frac{1}{2}$ in. deep, and a taper gib. The very small surface is not sufficient to resist the side strain of a cam, which is used on two of the operations, and the height is not sufficient to use a straight gib with set screws. It is usually necessary to replace the regular cross-slide with a special cross-slide, and when doing so it is much simpler to use a straight gib with set screws, rather than a taper gib.

7 To sum up, a manufacturer starting to make shrapnel would be well advised to consider the following suggestions:

a Do simple operations and use simple machines. Do not try to do several operations at one setting, and do not buy automatics, turret lathes or other complicated machines.

b A pretty safe and satisfactory plan is to get a quick start at some fraction of full intended capacity and to add equipment and build up production after some experience has been gained.

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c Suitable purchased machines for making a quick start would be regular cutting-off machines, regular engine lathes 16-in. to 24-in. swing, simple single-purpose lathes, regular or special grinders, and such special machines as bottling presses, band presses and band lathes.

d It will be worth while to consider the organization of a lathe-building department to supply many of the machines required to increase the capacity. This department might also undertake the making of air chucks, waving devices, and other special attachments, and thus relieve the tool room. Later, this department would become a repair department, which is an important and busy department when work is being pushed day and night.

8 *8-In. Howitzer Shells.* The British 8-in. howitzer shell (Fig. 2) is forged with the base open. After finishing the shell, the base is closed with a screwed base plug called an adapter. When we undertook a contract for these shells, we decided to make most of the lathes and other equipment ourselves, and for that purpose organized a lathe-building department. These lathes gave very satisfactory results as to first cost, upkeep, and rate of production. They take up much less floor space than the standard or special-purpose lathes which we were offered and enable the machines to be grouped so that the work can be handled very cheaply. The longest beds of these lathes are 8 ft. 6 in., and many of them are 7 ft. and 5 ft. 6 in. long. The absence of countershafts is also a feature which enables the lathes to be closely grouped. The lineshafts run crosswise of the shop, while the work also progresses across the shop from operation to operation. Long tables for holding the work run lengthwise of the shop between the ends of the lathes. The operator takes a shell from one table and, after completing the operation on it, places it on the next table, thus avoiding trucking.

9 Experience on this shell has confirmed the principle of doing simple operations on simple machines. For example, at first we undertook to rough-bore, ream and counterbore at one setting, but soon found it was better to make three separate operations on three different machines. The only operations which are done at the one setting are those which it is essential to have concentric. Thread milling had been superseded by tapping. We know of other manufacturers who have tried to make this same shell by doing a large number of operations at one setting and have made special machines for that purpose. They have, however, since discarded this plan and

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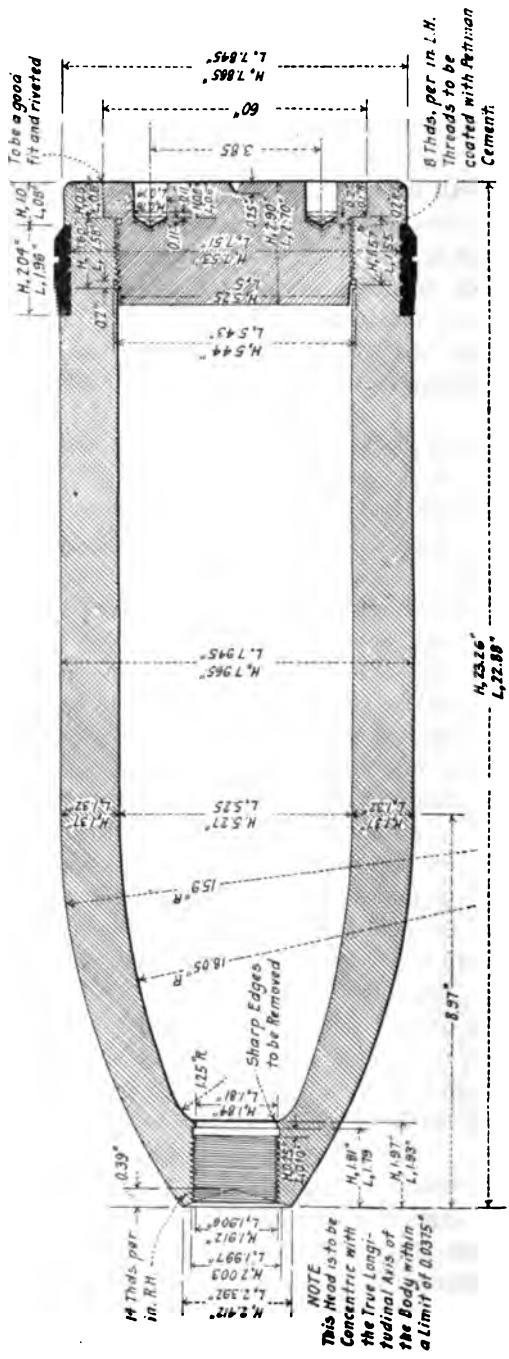

FIG. 2 BRITISH 8-IN. HOWITZER SHELL

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have come around to the general principle of doing one operation at a setting.

10 While the special-purpose lathes which we have built for this work have proven very satisfactory and have a number of advantages over purchased machinery, yet it took some time to get them designed and built. As in the case of shrapnel, the manufacturer would be wise to purchase a portion of the machines necessary to get a quick start at some fraction of the desired ultimate capacity.

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No. 1592*e*

PRACTICAL WARTIME SHELL MAKING

By Lucien I. Yeomans, Chicago, Ill.
Member of the Society

SO many utterly foolish statements have been offered the public in regard to the manufacture of munitions and the possibility of this or that automobile factory or implement works, or other equally ill-adapted shop being turned upon very short notice into a shell factory, that it seems well to consider of how little value for the manufacture of munitions is the present equipment of the average shop.

2 It should be emphasized that, outside of the already existing munitions plants, the old equipment which manufacturers brought to the new business of shell making consisted mostly of their money, their credit, and the nucleus of an organization. Even the old floor space was infrequently used. The machinery and tools were more than ninety per cent new, and it is significant that the greatest success has been made by those companies which were not even owners of machine shops of any kind.

3 All of the equipment enumeration and listing that has been going on may be of use in some way that is not now quite plain, and the so-called "educational" orders that we hear something of may do good in some way not yet clear to us, but the only thing we are sure of is that very little of tradition, precedent, and pure theory is observed in the conduct of a great war. Witness the methods of the submarine, and the use of liquid fire and poisonous gases; to say nothing of the stories of even darker deeds and more atrocious methods of man-killing.

4 War seems to take less care for the method than for the result, and the practical side of a war bears the same relation to the purely theoretical side that a bar-room fight between lumberjacks does to a properly refereed boxing match held under Marquis of Queensberry rules.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of The American Society of Mechanical Engineers.

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5 It is well for the mechanical engineers and the manufacturers to review carefully accepted methods of munitions production and to ascertain just what time-honored precedents may be abandoned, what red tape may be cut, what traditions of the mechanic arts are sacred but unnecessary, where the corners may be cut and the result attained economically, directly, and without delay.

6 It would seem ridiculous to construct an office building of steel and terra cotta for the field headquarters of an army division, but we see nothing strange in the equally ridiculous proposition of a nicely built permanent factory for the comparatively simple operations of machining shells.

7 There is a strange twist in our mental conception which permits an engine for one purpose to be nicely housed in a pressed-brick and tile-lined structure, while another equally expensive and nicely made engine may be properly located on the open deck of a vessel, entirely unprotected from the weather. It is the same deference to tradition that makes us assume that machine tools must be guarded from every exposure, and we fail to see readily that their performance would be equally good for unusual service if they were heavily coated with rust on every idle surface.

8 The suggestions made here for emergency factory construction are to be understood as applicable strictly to emergency conditions and to meet a demand for an unusual amount of ammunition with the least possible delay and in no way as suggestions for permanent private or Government arsenal construction.

9 First must be considered locality with reference to labor supply and transportation. Within easy reach of all our large centers of population may be found level, unoccupied, naturally well-drained acreage that is suitable for the purpose and that is gridironed by railroads. These are the sole requirements for such a plan.

10 The essential difference between this method and the conventional one is in the assumption that this particular machine work is no more an indoor occupation than is carpentry, bricklaying, car repairing, or structural ironwork, and that in such emergency it should promptly be decided that outdoor equipment is satisfactory.

11 Final inspection, cleaning, painting, tool making, etc., would be provided for in fully enclosed buildings at the delivery end of the plant; but the large part of the work would be performed with the lightest kind of shelter over machines, operators, and transfer track, and in the opinion of the writer circumstances would not always justify even this.

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12 The dimensions of the plant should be determined by the size of shell to be manufactured, and units of a given hourly capacity would be located between, and perpendicular to, two lines of railroad siding at the ends of the plant. One track would be entirely a receiving track and the one at the opposite side a shipping track. The distance between the tracks would represent the proper length of each unit to avoid congestion and afford the simplest movement and transfer of product.

13 The number of units required, as so determined, would establish the other general dimension of the plant.

14 Assuming that the shell was to be the well-known British 9.2-in. high-explosive and the required output 250 per hour, the general dimensions of the plant would be approximately 1000 ft. long by 300 ft. wide, and it would contain six units each capable of producing 42 shells per hour.

15 Each unit, commencing at the rear of the plant, would start with an unloading platform and extend in a double row of opposed machines for the different operations toward the finishing end, where the machinery installation would be replaced by hand operations and inspection, to the packing and shipping track.

16 From the end of the machine installation to the finishing end a single-story shelter would be built to house these operations and also the tool-maintenance sections.

17 All machine tools would necessarily be horizontally belted, but since space is not considered, the convenience of having all transmission machinery within easy reach is a consideration.

18 In the construction of the plant, lines of concrete piers would be located to carry the lineshafting, storm-water drains would parallel the lines of piers, concrete foundation walls for the machine tools would come next, and transfer tracks intermediate the machine foundations.

19 Throughout the length of each machine-foundation wall would extend a cutting compound drain to a sump and pump at the end of the line or at intermediate locations. From each concrete pan under or at the machines would extend a chip channel, having a slightly raised bottom, connecting with chip tanks sunken in the ground and covered, but readily removable by the cranes.

20 Between each two rows of machines would be an industrial railway upon which would be operated platform cars for transfer. At each machine would be car-floor-height platforms from and to which all tools and material would be transferred.

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21 Such a complete plant could be erected and operated to capacity within 60 days from the time authority was given to build it.

22 The purpose of this paper is to invite discussion, suggest a practical departure from the conventional, and present a method of emergency construction that it is hoped will be of some benefit.

23 Carrying ideas of the same kind into a scheme of preparedness would open a way by which the National Government could insure the completion and delivery to shell manufacturers of all necessary machine-tool equipment in the least possible time at a cost so low as to be negligible in comparison with the estimated figures for preparedness in other ways.

24 A complete series of machines for all shell-making operations could be designed along lines that would permit of their construction in immense quantities within 30 days from the time when the necessity for them arose, and at a rate of output that would supply any conceivable demand within the following 60 days.

25 Many such machines have already been made and put into service, and the practicability of such performance has been definitely proven in the last two years, one company having accepted orders for hundreds of machines on the guaranteed deliveries of "Commence in thirty days and ship five per cent of any-sized order every working day thereafter."

26 The United States Government could easily be prepared to deliver such machines in the desired daily quantities within 30 days by the following method:

27 In each selected industrial center establish a Government storage plant in which would be stored the necessary patterns, jigs and equipment to make such machines; and in which would also be kept a list of the plants in the territory equipped to make the required parts. Upon order from Washington the patterns would be shipped to the designated foundries and, beginning with the third day, castings would be received at the rate of one casting a day per pattern. It would probably require about three weeks to manufacture the various working parts of the machine, but within 30 days at the outside completed machines would be ready to run in the munition plants. The number of machines added to the equipment daily would be the same as the number of patterns from which castings were made. This record could be bettered by stocking in the warehouse the various machine parts, aside from the large bed castings, sufficient to make up machines of a desired daily output during the period found necessary. If this were done, completed machines could be deliv-

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ered to the munition plants within a week of authorization by the Government.

28 Ten such manufacturing centers could be established, as, for example, Philadelphia, Cleveland, Cincinnati, Buffalo, Pittsburgh, Minneapolis, Milwaukee, Birmingham, St. Louis, and Chicago, and within 30 days each unit could be producing shell-making machines at the rate of from 10 to 40 machines a day, depending on the size and nature of the machine being produced. Moreover, the total cost to the U. S. Government for the patterns, jigs, and equipment necessary for such a plan of preparedness would be approximately but $1,000,000.

29 Retrospection on the days of 1915 when manufacturers were begging for standard machine tools with which to make shells and were given deliveries of eight to eighteen months, shows the necessity for an entirely different provision of emergency machines.

30 To depend at all on current stocks or to hope to utilize to any extent the working equipment of existing shops is equally ill advised. To "cut from new cloth" in such an emergency as wartime conditions is the only method that promises success, and there is promise of nothing but disappointment in the attempt to adapt existing shops and machinery.

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No. 1592*f*

MUNITIONS DESIGN FOR QUANTITY MANUFACTURE

By J. E. Otterson, New Haven, Conn.
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THIS paper deals with the question of the relation of design to quantity manufacture, with particular reference to the problem arising from the undertaking of quantity manufacture under abnormal conditions, and especially by manufacturers who may not have previously manufactured the particular product in question.

2 The term *design* must be broadly and specifically defined, and will here be taken as including not merely the general conception of the particular product which might be termed the *inventive design*, but also the full consideration by the designer of all questions affecting the design, manufacture, and service. It is obvious that the design must lend itself to abnormal manufacturing conditions. The term *design* will therefore be here understood as including the determination of all the limiting conditions which will permit the product to fulfill the purpose of the design. In other words, the design must define not merely the ideal but also the limits allowed, and must provide all consequent necessary data to the manufacturer.

3 Quantity manufacture should not be undertaken when the design is in the experimental stage. Models and samples should first be made and thoroughly tried out to the satisfaction of the designer, the manufacturer, and the consumer. Such models should embrace the limits of tolerances and thus serve to test the judgment of the designer in establishing such tolerances.

4 It is essential that the designer and the manufacturer recognize in full their respective responsibilities. The designer is responsible for the proper functioning of the completed product, provided it fulfills the specifications set forth in the design. The manufacturer is responsible for fulfilling the specifications set forth in the design.

5 The designer should make his design and specifications so

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clear, precise, and complete as to preclude any possibility of subsequent misunderstandings as to the exact intention of the design and as to the responsibility for any failure to function.

6 Standards of design should be absolute and not relative, expressed in terms of standard units of measurements and not in terms of relative exactness involving personal opinion and judgment as to the relations existing.

7 Designs for quantity manufacture usually prescribe some requirements as to interchangeability, and presuppose a system that is commonly called *interchangeable manufacture*. The term *interchangeable*, as frequently used, is indefinite and relative and should not be used by the designer as a save-all to care for omissions from the specifications or as a substitute for the exact and absolute expression of the requirements of the design in terms of standard units of measurements. The term *interchangeable* has some significance as evidence of broad intent and general purpose, but is so lacking in exactness as to form no satisfactory basis for contractual or other obligations. It is, therefore, a dangerous term and should be used only in a supplementary sense.

8 There are degrees of interchangeability. For example, the components of a Ford automobile are interchangeable. We can purchase a component at a service station, and it can be installed in the car without special fitting and the car will operate, according to the Ford standard. Similarly the components of a Pierce-Arrow car are interchangeable; we can purchase a spare part at a service station and install it in the car and the car will operate according to the Pierce-Arrow standard. The installation will probably be more difficult than in the Ford because of the closeness of the fit and the refinement of the workmanship. In each case we have interchangeability, but we can scarcely say that there is the same degree of interchangeability. In other words, if interchangeability is to be measured by a mere exchange of components without reference to their subsequent fit and functioning, the Ford car is a more interchangeable product than the Pierce-Arrow, and the wider the tolerances and the less exacting the fit the more easily may the interchange be effected, and so the greater degree of interchangeability.

9 Do not fail to note that the Ford degree of interchangeability is characteristic of quantity production, whereas the Pierce-Arrow degree of interchangeability is characteristic of unit production on small volume. Under no circumstances should the mistake be made of trying to get Pierce-Arrow quality at a Ford price.

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10 Interchangeability increases in difficulty of attainment in ratio to the complexity of the product, the volume of manufacturing, the continuous operation of equipment, the abnormal and rush conditions in manufacturing accompanying national emergencies, the employment of unskilled and untrained labor and of labor having natural qualifications lower than those desirable for the work in hand. We must recognize that cutting tools lose their edges and exact form through wear, that machines do not continually remain in exact alignment and adjustment, that materials do not run absolutely uniform, and that the human element is a variable one. By reason of a combination of adverse conditions, absolute interchangeability may be impossible of attainment.

11 The designer must recognize therefore that peace-time standards of exactness cannot be maintained under war conditions, and that the standards of a factory that has been making a given article over such long and continued periods of time as to permit of the tuning of material and the training of personnel to exact repetitive performances, cannot be applied to the factory that must expand its facilities many-fold over night and deal with untried equipment, processes, and personnel.

12 In peace time the designer may quite properly seek to establish standards with such restricted tolerances as to enforce a high engineering standard, in order to preclude all possibility of failure of his design, and insure the success of his own work by placing a greater burden of accomplishment upon the manufacturer, but where the problem is one of earnest preparedness for war, the interest of the individuals must give way to the common good, and they must recognize a common purpose free of all antagonism and each give to the other all the tolerance that is possible, with the provision of a satisfactorily functioning product under urgent adverse conditions.

13 The problem before the designer of products for quantity manufacture under such conditions is therefore to give the manufacturer as *wide latitude* as possible without embarrassing the functioning of the product, and the suitability of the design to quantity manufacture under war conditions may properly be measured by the extent to which it meets this requirement.

14 It is recognized that this places upon the designer a decidedly heavier burden than is ordinarily assumed by him, but it is necessary that this should be the case if the design is to lend itself to the most rapid manufacture under the adverse conditions presumed.

15 This can best be accomplished by establishing as an essential

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part of the design a definite system of gaging, including the determination of gaging and holding points the control of which will control the functioning of the product, and prescribing tolerances at such points that are possible of attainment under the abnormal conditions of manufacturing under discussion.

16 It is the practice of some designers and manufacturers to prescribe exact dimensions as between two gage points and to establish no tolerances in connection therewith. The intention is that the manufacturer shall work as near to the absolute measurements as possible. Obviously this establishes no standard whatever. Since it is impossible to work to exact measurements, it places an unreasonable burden upon the manufacturer, who must assume the responsibility of prescribing the tolerances and instructing his help accordingly or, failing to instruct his help, permitting them to prescribe the tolerances according to their own judgment — obviously a loose method of operation. Every gage point should therefore have the tolerances clearly defined by the designer and these tolerances should be acceptable to the manufacturer and, once accepted, should be adhered to. To prescribe tolerances less than required for proper functioning is uneconomical since it demands unnecessarily exact operation and enforces extreme inspection practice, with consequent unnecessary rejections and reworkings.

17 Absolute requirements or measurements are justifiable only as applied to unimportant points or parts, where it may be safe to leave the question of tolerances to the judgment of the operator or of the inspector. In other words, we apply absolute measurements to those points about which we are not particular; where exactness is required tolerances should in all cases be provided in connection with the design.

18 In addition to providing a workable system of gaging, the designer must give consideration to materials and processes of manufacture. The materials prescribed by him must be such as to be readily obtainable in the broadest possible market under the abnormal conditions existing. It is important that the specifications for materials provide as great latitude as practicable and that no restrictive requirements be included which will unnecessarily prevent the use of commercial material. In addition, the materials prescribed must not present any serious difficulties of working nor place an unnecessary limit upon cutting speeds, nor unnecessarily increase the consumption of cutting tools. The importance is obvious of avoiding in the design elements which will require difficult and complicated

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cuts or other processes which will limit production or require experimentation with manufacturing methods.

19 The responsibilities of the designer and the manufacturer are further defined by consideration of the problem of inspection. Inspection should be of two kinds and for two purposes:

a ***Process Inspection*** — the inspection of the work in process to determine the satisfactory performance of the operations;

b ***Product Inspection*** — the inspection of the completed product to determine its satisfactory functioning qualities and its acceptability for the purpose for which it was designed.

20 The process inspection is obviously the responsibility of the manufacturer, and is his assurance that his manufacturing facilities are performing according to the standards set, his guide for the correction of manufacturing abuses or shortcomings, and his protection against the rejection of the completed product.

21 The product inspection is obviously the responsibility of the organization that is going to use the product, and is at once an inspection of the design and of the manufacture.

22 If, in connection with the product inspection, the product should be found not to function properly and yet pass a satisfactory process inspection — that is, come within the tolerances laid down by the designer — the responsibility is obviously with the designer, and the adjustment must be between him and the consumer of the product.

23 To summarize, the design should satisfy the consumer, the manufacturing conditions, and the technical laws applying to it. It should accomplish these by embracing the following qualities:

a The design must be

Complete	Past the experimental stage
Suitable for its purpose	Readily manufactured.

b It must include

Definite gaging system	Definite standards
Broad tolerances	Elimination of personal equation.

c The materials must be

Easily obtainable	Easily machined.

d And, finally,

The basis for inspection must be definite and equitable, and the division of responsibility between designer and manufacturer must be clearly established.

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No. 1592*g*

PROCURING MATERIALS FOR MUNITIONS

By C. B. Nolte, Chicago, Ill.
Member of the Society

AFTER the first few months of the present war, General French of the English Army said: "The problem set is a comparatively simple one — munitions — more munitions — always more munitions." The General's statement is undoubtedly true to a large extent at least, as it has been brought home to us by the European conflict that munitions certainly do constitute a most important problem in a war of any magnitude; but there are probably many manufacturers in this country today who will not exactly agree with the General as to the simplicity of the problem.

2 The United States is exceptionally fortunate, however, in the possession of extensive and valuable deposits of the principal metals and materials for explosives required for manufacturing munitions. Of the world's supply this country normally produces approximately 40 per cent of the coal and iron, 60 per cent of the copper, 65 per cent of the petroleum, 32 per cent of the zinc, and 33 per cent of the lead. It is apparent, therefore, that our domestic supply of the most important raw materials is ample for the manufacture of artillery ammunition, guns, cartridges and vehicles, which probably constitute the class of munitions that is required in the greatest quantity.

3 The coal is supplied from the Appalachian, Central Mississippi Valley and other fields of lesser importance, and the iron, which is the essential of the present guns, armor plates, projectiles, shrapnel and high-explosive shells, is secured principally from the Lake Superior region and the Alabama district. The chief sources of copper are Arizona, Montana, the Upper Peninsula of Michigan, Utah, New Mexico, Nevada and California. The petroleum production comes principally from the Mid-Continent, California, Appalachian and Gulf fields. Zinc is furnished from Missouri, Montana, Colorado,

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Wisconsin, Idaho and New Jersey, while Missouri, Idaho, Utah and Colorado supply the majority of lead.

4 This country, too, produces some chromium, vanadium, tungsten, and ores of lesser importance, but not in quantities sufficient for its needs for war munitions. It depends upon Rhodesia and Canada, Peru, and Burma and Portugal, respectively, for the deficit. It is true, also, that the United States is lamentably deficient in the production of nickel, which is an indispensable constituent of gun and armor-plate steel and armor-piercing projectiles. While Canada has been the principal source of our supply of nickel, a large amount of the ore has always been sent to this country to be refined. Tin is supplied to us mostly through Malaya, Bolivia, Banca and Siam, but is not such a necessary metal as nickel, and some substitute alloys have been used successfully. Gold, the prime requisite in the purchasing of munitions, is supplied in abundant quantities from our western and Alaskan mines.

5 Rubber, so necessary for trench waders, tires, cloth, ground sheetings, horse troughs, etc., is imported principally from Malaya, Sumatra, Ceylon and South America, but in stress of necessity synthetic rubber and other substitutes might possibly be manufactured with even greater success than is now attained. A strenuous "back to the farm" movement would result in the needed supply of grains, foods, cotton, horses and mules.

6 The United States Government arsenals are entirely inadequate, in time of war, to supply the needed products for war use, and this duty will fall, to a large extent, upon private industries. The amount of munitions that has been supplied during the European war is no criterion of the amount that can be produced in this country. Many concerns that have participated in this new industry built entirely new plants for that purpose in order not to interfere with their increasing domestic trade. In addition to innumerable smaller manufacturers, there are over 35,000 manufacturing and equipment concerns in this country, each doing an annual business of over $100,000. Almost every industrial plant has operating equipment suitable for producing some munition part.

7 The manufacture of shrapnel and other shells does not require special machinery, and car-building and car-material plants, motor-car factories and forge and machine shops are equipped to participate in this work. Watchmaking, typewriter, printing-machinery, office-equipment, scientific-apparatus and electrical factories, as well as many other small machine shops, have been readily adapted to the

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manufacture of shrapnel and high-explosive fuses. The majority of machinery and locomotive manufacturers have machined shells. In addition, car and locomotive builders can construct field kitchens, ammunition wagons, gun carriages and conveyances. Optical and jewelry factories are producing sights, aiming devices and periscopes.

8 It requires more special machinery to produce small arms and small cartridges satisfactorily, but even interesting and surprising resourcefulness has been exhibited in the manufacture of these in ordinary plants.

9 Only powder manufacturers, however, are able to make the necessary explosives. The most important materials used in explosives today are obtained from coal tar, a by-product of coke ovens. Coal tar and its derivatives are produced principally by the various steel companies, and whereas there was but one concern recovering benzol and toluol before the war began, nineteen concerns had constructed new plants for this purpose by the end of 1915.

10 The motor truck has proven to be an extremely necessary part of army equipment; but by means of new jigs and fixtures, the many pleasure-car factories, with their ever-increasing outputs, are readily converted into motor-truck factories. Aeroplanes, most important for fire-directing, are now being made upon a commercial basis in this country by over twelve firms. In addition, there are over forty factories producing a small number of machines of some special or experimental type which can be standardized in war time. On account of the short actual flying life of the aeroplane, however, it will be necessary to adopt extreme measures to bring the production to a satisfactory figure.

11 Since, strictly speaking, munitions include all supplies and equipment necessary in war, with the exception of men and money, only the characteristics of the more important materials can be considered within the limits of this paper.

12 The gun proper of the usual field gun is subjected to a suddenly applied pressure of from about 35,000 to 40,000 lb. per sq. in. and is generally made of nickel steel of over 90,000 lb. per sq. in. tensile strength, 60,000 lb. per sq. in. elastic limit, and an elongation in 2 in. of 18 per cent. Rigid inspection and tests of this material are necessary before it is worked. The artillery wheels, springs, hollow axles and recoil cylinders of field guns are made of ordinary materials used at automobile-wheel factories and forge plants.

13 The two principal types of projectiles are the shrapnel and high-explosive shell. The shrapnel body is not intended to break or

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explode when subjected to an internal pressure of about 20,000 lb. (the force exerted when the charge leaves the shrapnel), and is made of steel with a yield point of from 80,000 to 100,000 lb. per sq. in. Further, American shrapnel must, when finally treated, give a tensile strength of 110,000 lb. per sq. in. in some types and 120,000 lb. in others, with an elastic limit of 80,000 lb. and 90,000 lb. per sq. in. elongation in 2 in. of 15 and 16 per cent, and reduction in area of 40 and 45 per cent, respectively. Steel for this purpose is furnished by the steel mills, and contains: carbon from about 0.35 per cent to 0.45 per cent, manganese 0.50 to 0.80 per cent, phosphorus and sulphur not over 0.04 per cent each, chromium 0.70 to 1.20 per cent, vanadium 0.12 to 0.24 per cent.

14 European shrapnel is made of steel of about the same properties with probably a slightly higher carbon and manganese, and generally without the alloying of chromium and vanadium This latter steel, when finished, gives a tensile strength of from 117,000 to 130,000 lb. per sq. in. and yield point of about 80,000 lb. per sq. in., with an elongation in 2 in. of 8 per cent.

15 Shrapnel steel, as produced by the large steel mills in this country, is furnished in three different forms: rough-turned bars, forgings, and rolled-steel rounds. The latter form has been used with considerable success and exceedingly rapid production.

16 The ordinary shrapnel fuse is made of several brass parts, the material for which can be produced by modern brass foundries. The usual composition of this material is about 59 to 61 per cent copper, 37 to 39 per cent zinc and about 2 per cent lead, resulting in a tensile strength of about 45,000 lb. per sq. in., elastic limit 27,000 lb. per sq. in. and 30 per cent elongation in two inches. The fuse bodies and caps are generally forged, whereas the timing rings and other parts can be cut from brass tubes. The brass cartridge cases which hold the propelling charge for the shrapnel are drawn from brass disks cut from bars rolled by the various brass rolling mills. There is nothing unusual in the specifications for cartridge-case material, copper varying from 66 to 73 per cent according to different purchasers' specifications, with zinc from 27 to 34 per cent, and with a tensile strength from 43,000 lb. to 54,000 lb. per sq. in., and an elongation of from 28 to 32 per cent in two inches. The usual specification allows a range of 3 per cent in the copper and zinc contents; for example, 69 to 72 per cent copper and 28 to 31 per cent zinc.

17 The high-explosive shell is made of steel and is intended to break into a large number of pieces upon impact and explosion. It

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is usually forged from steel rounds, billets, and cast ingots, with carbon from 0.40 to 0.55 per cent, manganese 0.40 per cent to 1.00 per cent, phosphorus and sulphur not over 0.04 or 0.06 per cent each, and silicon from 0.18 to 0.30 per cent. Some of the steel for this purpose also contains nickel not to exceed 0.50 per cent and copper not to exceed 0.10 per cent.

18 This grade of steel is easily produced by practically all of the large and small steel mills in this country and, in fact, has been produced already in considerable quantities for such purposes. The fuse for the high-explosive shell does not present the same difficulties as that for shrapnel, and is usually made of ordinary steel and copper alloys.

19 The first problem in the procuring of shrapnel, high-explosive shells, fuses and cartridge cases is the delivery of suitable raw material. Care must be taken, therefore, to secure steel and brass of the proper chemical composition and physical characteristics. In addition to a careful study and understanding of the specifications and drawings, one of the most effective and economical means of obtaining the desired material rapidly and without excessive loss has been found to be the inspection of the material at the rolling mills before it is shipped to the finishing plants, by an experienced and trained organization.

20 Most specifications for shell steel stipulate a discard of 20 to 40 per cent from the top of the ingot to prevent loss or failure due to piped and unsound steel; inspection at the mill includes a supervision of this feature as well as the proper chipping of surface cracks and seams in the billets or rounds themselves, so that forging and machining will proceed with a minimum loss. The inspecting firm, too, in addition to this surface inspection, witnesses the prescribed physical tests and makes independent check chemical analyses. The heat treatment, which is so vitally important and which has been the prime cause of much avoidable delay and expense, varies, of course, with the chemical composition. Most concerns engaged in producing steel munitions during the past few years have found it advisable to employ such services at their own expense. Considerable loss, too, has been experienced in the manufacture of brass cartridge cases on account of attempting to draw defective disks, and inspection of these disks as sheared from the bar at the brass mill has been found to be of considerable value in maintaining production of the finished cases with a minimum loss of time and labor. The independent inspection provision, therefore, increases the acceptable percentage of the finished

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output when the product is presented finally to the government inspectors.

21 The majority of commercial explosives are not suited for use in shells on account of their inability to withstand, without explosion, the shock of firing from the gun. Smokeless powder is produced by special plants which treat cotton fiber with such materials as nitric and sulphuric acid, alcohol and ether. Nitrogen, used in the manufacture of nitric acid, is chiefly derived from the sodium nitrate found in Chile, but European nations are now obtaining a large amount of nitrogen from the air by the fixation process. Pyrites for making sulphuric acid is found in this country, although much of the best is imported from Spain. The United States manufactures ether and alcohol in abundant quantities. Glycerine, a by-product of soap manufacture, is produced in large amount at home. Cordite, the explosive which has come into such great favor because of its combination of propellant and high explosive qualities, is obtained by further treatment of gun cotton and nitro-glycerine with acetone, which is a product of wood distillation and which is also obtained from a special fermentation of starch. Trinitrotoluol is obtained by nitration of toluene, which constitutes about 36 per cent of crude benzol, a by-product of coke ovens.

22 Trinitrotoluol possesses an explosive force of about 119,000 lb. per sq. in., while the explosive force of picric acid is about 135,000 lb. per sq. in. Owing, however, to its propellant qualities and the fact that it does not form dangerous salts by combination with iron and other metals in contact, trinitrotoluol is superior to picric acid as a war explosive. Picric acid does yet, however, play an important part in priming compositions and propellant powders. It, too, is obtained from coal-tar derivatives.

23 Although, as has been outlined, the United States is well equipped to furnish the principal materials for munitions, it is apparent that there are many other phases of the problem which it has not been possible to consider here. If the requisites of war are to be successfully met, every industrial worker, whether he be engaged on the farm, in the mine or in the factory, has an important task to perform; every manufacturing plant has a definite obligation; and all the resources of our country must be systematically brought to their utmost utility.

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No. 1592*h*

LIMITS AND TOLERANCES FOR THE MANUFACTURE OF MUNITIONS

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Non-Member

THE purpose of this paper is to direct attention to some of the practical aspects of the question of limits and tolerances as customarily applied to the manufacture of munitions, rather than to attempt to establish standards of high technical value in assigning definite limits to the several classes of dimensions involved.

2 Most mechanical men who have had recent experience with munitions manufacture will agree with the statement that their troubles have not to any great extent been due to inherent difficulties with the tolerances in general; but have principally been caused by such factors as incomplete or inconsistent drawings and specifications, and lack of mechanical judgment on the part of inspectors in interpreting the drawings and specifications and in the use of limit gages. In fact, these aspects of the subject are of such major importance that it would seem that technical refinements may be postponed until standards of practice have been established with respect to these factors.

3 The average munitions drawing is fairly open to criticism and leaves much to be desired in the way of clearness and consistency. Such defects as the following are often encountered:

a Flat dimensions without any tolerances

b Dimensions with one tolerance only, either plus or minus

c Overlapping tolerances on two parts which assemble together

d The sum of the tolerances on intermediate dimensions is not in agreement with the tolerances on the overall dimension

[1] With General Electric Company.

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e No limits are specified as to permissible eccentricity between concentric cylindrical surfaces, or between two parts which assemble together

f In the case of screw threads on two parts which assemble together, but where interchangeability is not required, no specifications are given as to the nature of the fit.

4 Defects *a* and *b* can be readily remedied by establishing an invariable rule that all dimensions must be the mean dimensions with equal plus and minus tolerances.

5 Defect *c* usually occurs in the tolerances for external and internal threads on two parts which assemble together, and is occasioned by losing sight of the fact that the maximum external thread must be slightly smaller in diameter than the minimum internal thread, in order that these extremes may assemble properly.

6 Defect *d* can best be avoided by establishing the invariable rule that all dimensions in the same direction must start from a common reference line.

7 Defect *e* is a fruitful source of trouble to the munitions maker, and consequently in all cases where close concentricity of cylindrical surfaces is essential, definite limits of eccentricity should be specified on the drawings.

8 Defect *f* can conveniently be illustrated by considering the fit of a nose-piece or base-plug external thread, in the internal thread in a shell. In this case the nose piece or base plug virtually becomes an integral part of the shell after it has been assembled. In fact, it is common practice to finish-machine or grind these parts after they have been assembled, and in subsequent operations such as loading keep them together by similar markings. Manifestly all that is required from the standpoint of utility is that the nose piece or base plug should screw into the shell easily, but without too much looseness. As such threads are usually quite coarse, liberal tolerances are in order, but the dimensions and tolerances must be properly assigned in order to avoid the possibility of too much looseness. This can readily be accomplished by letting them overlap to some extent, which will of course result in producing some nose pieces and base plugs which will be too large to enter shells having minimum threads. This apparent difficulty is overcome by grading the nose pieces and base plugs, as, for instance, small, mean, and large. A mark can also be put on a shell at the time it is gaged which will indicate to the assembler which grade of nose piece and base plug to use.

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RELATION OF TOLERANCES TO WEIGHT

9 Perhaps the most striking defect, in shell drawings particularly, is the discrepancy between the tolerance specified for the weight of the shell and the variations in weight of the shell from making one to maximum external and minimum internal dimensions, and another to minimum external and maximum internal dimensions. As a rule, shell drawings and specifications allow a variation in weight of plus and minus one per cent of the mean weight for the smaller sizes and less for the larger sizes, whereas the extreme dimension tolerances would permit two to three times as much variation in weight. Furthermore, no dependence can be placed on the assumption that a shell machined to the mean dimensions will have the mean weight specified on the drawing. Whether or not these discrepancies are intentional or accidental the writer is not informed, but it seems obvious that the drawings should be revised.

10 From the standpoint of ballistics, uniformity in weight of shell is highly desirable, and consequently close weight tolerances are to be expected; but the drawings and specifications should sound a clear note of warning so as to prevent a manufacturer from proceeding on the assumption that the dimension tolerances can be used indiscriminately. Some tolerances bear evidence of having been added — probably to meet some difficulty in manufacture — without perhaps due consideration being given as to the extent to which the weight would be affected. In any event, it seems imperative that the drawings should be revised so that shells machined to the mean dimensions, and of steel of the specified quality, will have the mean weight.

11 If ballistic considerations permit, the weight tolerances should be increased, since they are at present the limiting factor. The drawings should plainly state that advantage cannot be taken of all the extreme tolerances on any one shell, if such is the case.

12 These considerations are not advanced as an argument against larger dimension tolerances than weight tolerances, since liberal dimension tolerances afford a maximum of munitions production; but rather to caution the manufacturer to consider carefully all possible combinations of the tolerances which will produce the greatest uniformity in weight of the finished product, and also to suggest to the ordnance engineer the desirability of plainly pointing the way to attain the desired results.

13 In this connection it seems desirable to call attention to

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another aspect of the proposition that liberal dimension and weight tolerances are advantageous, namely, that the operators of machines at the start of any organization will be largely unskilled, and in a large organization the breaking in of new operators will be practically continuous, so that the more liberal the tolerances are for each operation the greater will be the product of usable munitions.

THREAD TOLERANCES

14 Perhaps the most difficult operation in munitions manufacture is the cutting of internal and external threads within close limits. The Whitworth form of thread is particularly difficult to cut and has been the cause of endless trouble in recent munitions work. We all regard the rounding of the top and bottom of this thread as particularly iniquitous and we are apt to regard the United States form of thread as greatly superior. As a matter of experience, it is quite difficult to maintain the size of the United States form of thread within close limits. The requirement that this form of thread shall fit on the top and bottom, as well as on the all-important angle, is the chief source of trouble. The very existence of this requirement results in most of the fitting occurring at the top and bottom of the thread, rather than on the angle. It is practically impossible to avoid this condition since the tops of the threads on a tap wear away very quickly and therefore the tap does not continue to cut internal threads of full depth. As the thread gages are made of standard form, it is obvious that much of the work will not pass the gages, although perfectly correct as to angle diameter and pitch. To a less degree is the same condition true of dies and external threads. This defect is universally recognized in American machine shops and is quite commonly overcome by making the diameter of taps slightly larger than standard, so that they will cut an internal thread deeper than standard and also cut a larger hole or core than standard. This affords a clearance at the top and bottom for the external thread. It seems manifest that this necessary and customary practice should receive official sanction in the drawings and specifications for munitions, and that limits for these clearances should be specified.

INDIVIDUAL JUDGMENT OF INSPECTORS

15 Next in importance as affecting the manufacture of munitions is the question of mechanical judgment in interpreting the drawings and specifications on the part of the inspectors, and also in regard to the proper use of limit gages. Although many inspectors are men

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of excellent mechanical judgment and experience, a large number of necessity have not these qualifications. In fact, it would be detrimental to other lines of manufacture to require that only experienced mechanics be selected as munitions inspectors. It therefore seems that the obvious solution of this difficulty is to make the drawings and specifications so clear and comprehensive that men with little mechanical experience can become efficient inspectors. The specifications should clearly specify such details as kind and quality of finish for all surfaces, whether by turning or grinding, and if by turning whether the tool marks must be removed by filing. Some surfaces can, in the interest of maximum production, be left semi-finish-turned, and the specifications should in such cases so state. In general, this plan can be made most effective by basing the requirements of the specifications on actual results obtainable with modern machine tools, and all unnecessary refinements should be eliminated.

16 Regarding the proper use of limit gages, it is perhaps difficult to lay down general rules, but certainly such a fundamental one as that gages should never be forced can be advanced without hesitation. The writer has seen shells rejected at a loading plant for large rotating bands which had passed inspection at the works where they had been machined. The trouble was not due, as at first supposed, to a difference in the ring gages, but simply to the fact that the inspector at the works where the shells were made insisted that the minimum ring gage should not go over the copper bands to the slightest extent but accepted bands over which the maximum ring gage could be forced; whereas at the loading plant the inspector required that the maximum ring gage should slide over the bands by its own weight. The attitude of the inspector at the works where the shells were made regarding the use of the minimum ring gage forced them to work near the maximum limit, and conditions were not improved by the rapid wearing of the maximum ring gage due to its being forced over the work.

MACHINE-TOOL LIMITATIONS

17 The limits of accuracy attainable on machine tools must be taken into consideration in determining how limit gages should be used. The screw thread affords a good illustration of this point. In a part where a threaded hole goes entirely through the part, it is not very difficult to cut threads of uniform diameter in the sense that the thread is uniform throughout its length and that it does not taper. In bottom-tapping a shallow hole, however, or in cutting a

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short external thread both are apt to taper slightly, or at least the first thread or two will be thin. In the first case it is perfectly proper to require that the maximum thread gage shall not enter at all; but the second case manifestly demands different treatment. A rational rule would be to allow the maximum thread gage to screw in one-third or one-half the depth of a shallow not-through hole, and the same allowance should be made in the case of a short external thread. This proposition should be judged from the standpoint of utility rather than ideality, particularly when one stops to consider that the mechanic can, by cutting the external thread in the proper direction, make these inaccuracies tend to balance each other.

18 To sum up, maximum production, which is the principal aim of any revisions, can be most readily attained by increasing the weight tolerances in the case of shells particularly. If, however, the ordnance engineer cannot allow any greater variations in the weight of shells, then, at least, the alignment of mean weight with mean dimensions, as outlined in the foregoing comments, will, it is believed, prove to be an important step in the right direction. As regards other munitions, where weight variation is not so important, much can be accomplished by aligning the dimension tolerances with the capacity for accuracy possessed by modern high-speed machine tools.

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No. 1592*i*

GAGES AND SMALL TOOLS

By Frank O. Wells,[1] Greenfield, Mass.
Member of the Society

OF first importance in the manufacture of rifles, guns and munitions of war is gages. There are many types of gages, but the one used in the manufacture of munitions is the dimension or limit gage. Whatever the instrument used, it must measure accurately and rapidly, and must also be durable, as very slight wear will destroy the accuracy.

2 It has been well said that if we can measure an article we can make it. The difficulty lies not in the making, but in the measuring; and our greatest obstacle in exact measurement is the human element.

3 In olden times the human element was the controlling factor in all operations. Work was done in very small quantities and was not interchangeable. Some work was good and some was poor, all depending on the man who did it. To meet the demand of the present day, we must have progressive manufacturing, where each man has only a small part of the work, and that part must be done by an ordinary workman. All this calls for a method of measurement different from that formerly used. Then we wanted one piece, now we want thousands of pieces, all alike and each one an exact duplicate of the other. This is easily accomplished by printed instructions and gages. With these we may start a large number of factories making war materials that will be one hundred per cent good, and also standardize the cost of production.

4 Improperly designed gages cause poor work and a lack of interchangeability, making the cost of production and the cost of assembling greater. Our Government should take advantage of the knowledge of this fact obtained at such great cost in the present war,

[1] President, Greenfield Tap and Die Corporation.

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and should standardize all its operations, gages and measuring tools, so as to avoid a repetition of mistake of this kind.

5 The Government should have, first of all, its blue prints prepared with the proper tolerance perfected by tests and careful practice. The sequence of operations, and the time taken to do the work, should also be perfected and put in printed form with the necessary cuts showing the set up, as well as the best way to handle the work, both in the operation and gaging. This would enable all factories to standardize their productions.

6 The importance of the best methods of measuring is illustrated in a report from the U. S. Ordnance Department in which is made the statement that the cost of inspection is from 10 to 12 per cent of the total cost of manufacturing. These are startling figures and indicate that the proper gaging methods had not been used.

7 The output of the U. S. Government arsenals for the year 1915 was $11,284,113.95; for the year 1916, $9,471,300. It has been estimated on good authority that this could have been increased at least 50 per cent without increasing the size of the plants, by having a larger supply of gages and tools. The cost of such tools and gages is estimated at 20 per cent of the total cost of the plant, which shows conclusively the need of gages and small tools.

8 If we were to make 100,000 rounds of ammunition per day in Government arsenals, it would require at least 100 arsenals the size of Frankford for the small-arms ammunition alone. This shows the necessity of using private factories, but the Government should own all of the gages, small tools and fixtures, to get the proper standardization.

9 To equip an army of 2,000,000 with the necessary rifles would take at our best rate of production four years, and at our present rate, eight years. This is one rifle to each man, and we should have five rifles to each man to take care of the wastage.

10 Now, to increase any of the present rifle plants to any considerable extent would take at least 18 months. This means new machinery, gages, tools, jigs, and fixtures and the breaking-in of the necessary new workmen. To start a complete new rifle factory would take from 24 to 30 months to produce rifles in any large quantity.

11 Few people realize that our Springfield rifle has more than one hundred parts and requires 1400 distinct factory operations. To produce 1,000,000 rifles requires $360,000 worth of gages for the original equipment, while renewals cost $400,000, making a total of

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$760,000. Each 1000 rifles made require 4800 gages. The renewal of the gages costs about 50 cents per gun. To make 10,000,000 rifles in 200 days requires at least sixty more arsenals than we now have.

12 The war material most talked about is ammunition, of which our Government uses about 17 sizes at present. The cost, including the upkeep of gages, used in the making of 1000 rounds of ammunition per day, with a steady production for 200 days, is at least $2,225,000. These figures have been carefully worked out by makers well versed in the manufacture of gages for ammunition. It has been estimated by good authority that we should be able to make at least 200,000 rounds per day. The vast importance of the whole gage question may readily be realized.

13 Of course some sizes of ammunition have to be made in much larger quantities than others. Careful estimates show the special jigs and fixtures would cost nearly double what the gages would. So far, the paper has only touched on ammunition and rifles. To have everything on hand necessary the figures given must be multiplied many times.

14 There are today some 3,500,000 people in Great Britain engaged in making munitions of war in over 4500 factories. In doing this work to advantage, each workman should at least have $25 worth of gages, tools and fixtures.

15 The majority of contracts taken for ammunition in this country were taken by manufacturing organizations without previous experience on war material, and in many cases without experience in the manufacture of large quantities of interchangeable metal parts of any kind. The drawings and specifications supplied were in nearly all cases incomplete from the point of view of such manufacturers, although these same drawings might have been sufficient in the hands of a trained organization familiar with the same class of material, but of only slightly different design — in other words, there were few experts in this country who had ever had actual experience in producing war material — therefore in the majority of cases the drawings and specifications had to be interpreted by engineers and mechanics with little knowledge of the exact functioning of all the parts involved. The gages first designed were generally inadequate; the tolerances and clearances allowed were not the best possible to insure economical assembling of the parts, with the result that a great many rejections were inevitable during the first months after production was attempted.

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16 More important, however, was the fact that the capacity of the toolmakers in this country was less than one-tenth that required to produce the necessary gages with sufficient accuracy, even if they had been correctly designed. The result was months of delay when the gages had been ordered from the few competent manufacturers, and a very high percentage of rejections after enormous expense in the case of gages which inexperienced workmen had endeavored to produce.

17 In one case, gages to the amount of $1,200,000 had been received by one war-material contractor from a large number of different makers. Eighty-five per cent of these gages were rejected on the first inspection, and many of them were never corrected within the necessary limits.

18 Our Government should provide itself with all the gages, tools, jigs and fixtures far in advance of any possible expectation of requirement, the cost is small, compared with the results obtained. This is a very simple business proposition — what every efficient manufacturing company would do.

19 It is a very poor policy to cut down on the number of gages and small tools. It is far better to use every labor-saving device possible. All this means a saving in high-priced labor, and this is very important in time of need when we cannot get the necessary skilled labor.

20 The papers are full of the talk on compulsory military training. Why shouldn't we have compulsory mechanical training? It has been said that for every man in the field we should have one man in the factory.

21 It is considered the best practice in manufacturing to put the thought and money not so much in the large machinery as in the small tools. The most important of all are the gages, and these must be so designed as not to have any guesswork about it. We must know that every part is machined right. We must be able to say we know this is right, and not to say, I guess we are right.

22 To most people gages seem of small importance, but as this paper endeavors to show, they are quite the reverse.

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No. 1592*j*

THE IMPORTANCE OF INTELLIGENT INSPECTION IN MUNITIONS MANUFACTURE

By E. T. Walsh, Watertown, N. Y.
Member of the Society

A STRIKING example of the difficulties that may arise in inspection work has been afforded during the present war in one contract for the manufacture of 5,000,000 rounds of 3-in. ammunition for the Russian Government, which was completed by the contractor subletting the work among more than one hundred manufacturing plants in the United States and Canada, the magnitude of the work and the short time limit making this necessary. The contractor, for his own protection, had to inspect all the product as it was made by the subcontractors, and a corps of inspectors was required in each plant, the number of such corps being equal to the number of plants doing work. Great difficulty was experienced in getting men qualified to do this work, because there were practically none in this country who had experience in the manufacture of munitions, and but few available who had any kind of inspection experience.

2 To expedite the delivery of the finished product, the Russian Government placed its inspectors in the plants of the subcontractors, where they received the finished parts directly from the contractors' inspectors. Russia was as little prepared to provide the required number of qualified inspectors as was the contractor, and in consequence the manufacturer had inflicted upon him so-called inspectors who were selected from every walk in life, it seemed, except the mechanical.

3 The specifications for the ammunition were so drawn as to leave a great deal to be interpreted by the inspector, who was rarely qualified to intelligently pass upon the point at issue. The following extracts copied from the specifications will serve as examples:

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"There shall be no scratches, slivers or cuts on these parts. . . ."

"If, independently of the above, in order to ascertain the qualities . . . the Receiver shall deem it necessary to make . . . other experiments, the factory shall give him all necessary means for making such tests."

"For the measuring and verification of the projectiles the factory is under obligation to furnish a sufficiently vast, light, dry and warm room and place at full disposition of the Receivers as well as furnish cupboards for the keeping of verifying instruments, scales of sufficient sensitiveness, electric lights of sufficient energy, for the examination of projectiles and gross power."

"For the measuring of the projectiles the factory shall furnish the Receiver, for his exclusive use, all verifying working instruments . . . prepared according to the instructions, *as well as according to the indications of the Artillery Receiver.*"

". . . the finish of these surfaces must be brought to such a degree as is obtainable when working with a tool."

4 The slightest scratch or tool mark was soon magnified into a cause for rejection. One subcontractor claimed that he was required to unbox several thousand shrapnel because the Russian Inspector found a flyspeck on the copper band of one of them! In spite of the fact that gages were called for by the instructions for certain gaging points, the inspectors were not satisfied with them, but asked to be furnished with others that were of a design that would be more searching and exacting. Under the clause governing the finish of the shell, the inspectors were soon demanding a finish that could only be obtained by buffing, and the unfortunate part was that the manufacturers had no redress, because there were no standards of finish established; there was no set of standard gages, nor was there anyone in authority to whom the contractor could appeal and whose decision was final.

5 Fresh from the experience of two years' struggle to produce work under such conditions, the writer is constrained to appeal for coöperation in the endeavor to standardize and systematize the production of munitions so that manufacturers will in future have definite instructions and standards to work to and in the case of honest differences of opinions a Bureau of Appeal where questions will be decided definitely and authoritatively.

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6 Drawings should be checked and rechecked until the possibility of error has been reduced to a minimum. Tolerances should be decided upon that will allow the greatest leeway compatible with good work.

7 Every effort should be made to make the specifications simple, clear, explicit and absolute. They should leave very little open to the discretion of the inspectors. The specifications should describe the gages to be used and how to use them.

8 The gages used should be as few as will check up the product in all of the important features. What these gaging points and their limits should be, should be determined by competent military engineers, working with the idea of getting a product that will meet all requirements and still be practicable, so that the quality produced will not be curtailed by unnecessary refinements. Exactness should be required where it is necessary, and where it is not necessary there should be no holding down to ridiculously close limits.

9 Corps of inspectors should be enlisted from our numerous manufacturing plants and thoroughly drilled in the use of gages and the meaning and intent of the specifications, with particular stress laid upon the fact that inspection should be made with the idea of accepting as many as possible rather than a high count of rejections.

10 Each manufacturer should be supplied with a set of correct sample gages with their masters and grand master by which the working gages should be made and checked.

11 An approved sample of the product to be made should be furnished to each factory to be used for comparing the same with the regular product when necessary. These samples should be official and product equal to sample should be accepted without question.

12 It is most important to have a bureau composed of qualified engineers to interpret specifications and render final decisions on all points that may arise. Manufacturers should have the right of appeal to this board and get its unbiased opinion. At this bureau should be kept on view officially accepted samples of all parts in the various stages of manufacture to be referred to when making decisions.

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No. 1592*k*

DISCUSSION ON MANUFACTURE OF MUNITIONS

THE following excerpts apply specifically to points raised in the preceding ten papers, Nos. 1592*a* to 1592*j*, inclusive. An extended account of the general discussion of these papers was given in THE JOURNAL for July 1917.

R. R. ADAMS,[1] representing the Bureau of Ordnance, said that its policy had been to direct its representatives to coöperate with the various manufacturing firms to which they were accredited in every consistent and proper manner, and to facilitate the manufacture and expedite deliveries wherever possible, provided that satisfactory and acceptable material was procured by the Government. Information was volunteered if it would aid manufacturing processes and at the same time did not violate confidential matters disclosed by other firms. He believed that all information and experience required for the manufacture of munitions should be pooled by the different plants so as to assist other plants, especially the new ones.

REUBEN HILL spoke from his experience in munitions manufacture in Canada. With respect to the organization of the industrial forces of the United States, he suggested that the Government take a more coöperative and guiding activity in relation to the manufacturer, thereby departing from the peace-time method of arbitrarily giving a contract, and then at a certain time sending some one forward to inspect the work, and either arbitrarily accepting it or rejecting it. He believed that the Society should be of great assistance to the Government in formulating an ideal coöperative industrial scheme, similar to that which had been adopted in Canada.

FRANK B. GILBRETH emphasized the importance of recording all details, including the time element, with respect to industrial

[1] Lieutenant-Commander, U. S. N.; Inspector of Ordnance, Munhall, Pa.

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operations, and said that the best method of doing any kind of work did not lie in the consecutive acts of any one worker, but was synthesized from records of methods of many expert workers. The micromotion film which he used to record workers' methods was the result of placing a timepiece that recorded the *time* element, and a cross-sectioned screen that recorded the *space* element, in the field of the method to be photographed. The pictures were taken at varying rates of speed, and then projected at the speed at which they were taken, at slower speeds and at more rapid speeds, in order to get different views of the operation being studied. The two aims were, first, to get all possible detailed information on the film, and second, to get this information off the film and into such form as would aid in transferring the information most easily and most efficiently to the learner.

R. POLIAKOFF,[1] referring to Par. 32 of Mr. Waldron's paper, instanced a case where a foreign government had given a contract of $84,000,000 with an advance payment of $10,000,000, and said he thought that the government in question could not be expected to advance 33⅓ per cent to the contractor, or $30,000,000, when the contractor's capital was less than one-tenth of that amount and all the surety companies in the country combined could not issue surety bonds to exceed $5,000,000 on any one contract. Small advance payments, he thought, were by no means the cause of the failure of some of the contractors, as Mr. Waldron had stated.

A. B. REYNDERS[2] submitted a written discussion in which he endorsed the statements in Mr. Coe's paper and outlined a method used by his company in the manufacture of high-explosive shells, which secured a large and continuous production after the equipment and operating force had been organized. A description of this method was given in THE JOURNAL, July 1917, p. 612.

H. G. BERTRAM wrote giving an account of the organization of the John Bertram & Sons Co., Ltd., Dundas, Ont., for the manufacture of 8-in. British howitzer shells. This organization, details of which were given in THE JOURNAL, July 1917, p. 612, was kept entirely separate from that of the plant proper, which was devoted

[1] 111 Broadway, New York. (Assistant Professor of Mechanical Technology, Technical Institute, Moscow, Russia.)

[2] Director of Production, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

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to the manufacture of machine tools. Referring to Mr. Yeomans's paper, he said that he believed there were shops in plenty already in existence which could be rapidly adapted for shell manufacture, and that the emergency factories advocated in the paper were unnecessary.

RALPH E. FLANDERS said he believed that the most valuable single asset of a firm starting the manufacture of anything was the vital organization of a group of men who were accustomed to working together, who knew each other and who had a good conception of their respective duties.

E. F. DU BRUL said that the smaller manufacturers wanted to do their full share, and that in Canada such concerns had been able to produce large quantities of munitions through coöperation with their manufacturers' association and their shell committees.

P. S. BOND,[1] referring to Mr. Walsh's paper on inspection work, emphasized the importance of closeness and accuracy in shell manufacture. This was imperative, particularly in the case of the moving barrage, where it had been found that if there was an error in the bursting point of the shrapnel of even as much as 25 yards, it would result in the killing of great numbers in the attacking force. At another time Major Bond addressed the meeting at length on matters connected with the entry of the United States into the war.

Topics related to the general subject of munitions manufacture, such as coöperation among manufacturers, problems of the small manufacturer, standardization of gages, the pooling of information, collection of data, etc., also drew forth considerable discussion, those participating being Harry E. Harris, Ira N. Hollis, W. H. Carrier, James Hartness, H. B. Coho, C. W. Rice, William Kent, Frank O. Wells, Chester B. Hamilton, Jr., Ralph E. Carpenter, M. W. Sherwood, Chauncey H. Crawford, H. Wade Hibbard, H. S. Bergen, L. P. Alford, F. A. Waldron, F. E. Rogers and John H. Barr. This discussion resulted in the appointment of the following committee to draft appropriate resolutions: Luther D. Burlingame, *Chairman*, John H. Barr, J. B. Doan, A. J. Baker, Reuben Hill, H. L. Coe, Harry E. Harris, and C. B. Hamilton, Jr. The resolutions as finally adopted after discussion are as follows:

[1] Major, Corps of Engineers, U. S. A., Cleveland, Ohio.

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RESOLUTIONS RELATING TO GAGES AND STANDARDS

WHEREAS: Serious delays have been experienced in other countries and this country in the production of munitions work; and rejection and unnecessary loss to manufacturers and its consequent shortage of labor and material due to lack of control of data and of standard means of measurement; and

WHEREAS: Great Britain, Canada and France have found standardization of measurement of all war material for both Army and Navy imperatively necessary to obtain uniform and reliable results, and have constructed an efficient organization which has proved successful in overcoming these difficulties; and

WHEREAS: Increased efficiency of our manufacturers would be promoted by the establishment of proper standards of measurement;

BE IT RESOLVED: That the Congress be urged to appropriate sufficient funds for expenditure through a suitable agency, to provide standards and adequate means of calibration, distribution and supervision of such standards; including means for calibration of working and inspection standards in the different centers of munitions manufacture.

Also that provision be made in this appropriation for the establishment of a central office for the collection and dissemination of information on the methods of manufacturing munitions and other supplies.

RESOLVED: That this Society endorses any efforts tending to promote the ends outlined above, and in view of the imperative needs of the present situation, most strongly urges immediate action.

RESOLUTION RELATING TO COÖPERATION BETWEEN MANUFACTURERS

WHEREAS: It is the patriotic duty of every manufacturer to facilitate and expedite the manufacture of munitions and other supplies for the Army and Navy;

BE IT RESOLVED: That an appeal be addressed to all manufacturers and engineers to coöperate in the dissemination of information and the interchange of data pertaining to methods of manufacture, systems of organization, design of tools, operation layouts and time studies, including what is generally known under the term "shop secrets" so far as they pertain to munitions manufacture.

RESOLUTION RELATING TO STATUS OF MEN IN THE INDUSTRY

WHEREAS: It is necessary to obtain the entire patriotic coöperation of every man who can contribute to the furnishing of military and naval supplies;

BE IT RESOLVED: That we urge upon the Government the necessity of indicating in some way the value and loyalty of men in service in the industries whose occupation is essential to the production of war supplies.

A further resolution, submitted by F. A. Waldron and calling for the establishment of a clearance bureau for information on the manufacture of munitions, on vote was referred to the Council of the Society with power.

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No. 1593

THE PROBLEM OF AEROPLANE-ENGINE DESIGN

By Charles E. Lucke, New York, N. Y.
Member of the Society

The aeronautical engine is emerging from the stage of invention to the stage of design, and this paper suggests steps to be taken towards the satisfactory solution of the problem.

It resolves the engine into a light, high-tensioned steel structure, consisting of seamless tubing and forged or welded steel parts, possibly formed in drop-forge dies. To this steel stress structure are added certain members, such as the piston, exhaust valve and guide, designed primarily for heat-flow conditions and not for stresses; and certain closing members, such as the ports for the intake and exhaust, which can be very properly cast in aluminum, and the water jacket; and the oil crankcase closure, which can be made of any material desired.

THE problem of the aeroplane engine appeals strongly to every engineer because it is a problem of the lightest power plant. The lightest weight of engine proper per horsepower is to be secured first by obtaining maximum mean effective pressure at maximum speed: in other words, the product of mean effective pressure and speed must be a maximum. At the same time the weight of metal per cylinder, or per cubic inch of cylinder displacement per working stroke, must be a minimum, —and with both of these factors the engine must be reliable in operation. So far, this reliability factor has been weakest, though lightness has been secured in engines good for short periods of running.

2 Not only must the metal weight of engine per horsepower be a minimum, but in addition the fuel weight to be carried must also be a minimum because, as can readily be seen, the fuel weight necessary for flights of any length predominates over the engine weight. For example, taking a half pound of fuel and oil per hour per horsepower as a fair value, it is readily seen how quickly that will catch up on engine weight when the latter is 4 or 5 lb. per horsepower.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of The American Society of Mechanical Engineers. Contributed by the Philadelphia Section.

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3 In undertaking an analysis of the aeroplane-engine problem from the records, the only conclusion that can be drawn is along the line of type. Data are almost entirely lacking. On the question of general engine types, attention might be called to a few points:

4 The air-cooled motor has entirely failed in comparison with the water-cooled motor — the reasons are perfectly sound and secure. The 2-cycle engine has given way to the 4-cycle type.

5 Fixed cylinders have prevailed over rotating cylinders. Odd cylinder arrangements of queer, freaky forms have all been relegated to the scrap heap in favor of a few modern arrangements. The standard cylinder arrangements of today, which are the survivors of what may be called the inventive period, or at least the first inventive period, are the six and eight cylinders in line and the eight, twelve and sixteen V's.

6 It really appears therefore that the one valuable result of all our experience has been the selection of a few typical arrangements which we are now compelled to study, as minutely as circumstances permit, for the purpose of standardizing and mechanically perfecting these particular types as standard machines which will run as reliably as our stationary engines and which can be manufactured as economically.

7 Taking up each of the factors of aeroplane-engine design that seems important, in as specific a way as seems proper, the first one to be considered is the value of efficiency and the relation of efficiency to minimum weight.

8 Plotting hours of running as abscissæ against weight of engine with fuel and oil as ordinates, for the air-cooled and the water-cooled types of motor, respectively, so that the intercept on the vertical axis represents the weight of engine metal alone, and the ordinates away from the axis represent the weight of metal plus fuel and oil, one finds that the two curves cross at some period of running beyond which, therefore, the water-cooled heavier engine, because of its lower fuel consumption, becomes lighter in comparison.

9 The metal weight of the water-cooled motor is about one and one-half times that of the air-cooled motor, and the slope of the combined-weight line of the latter compared with that of the former is as two is to one, — that is to say, the consumption of the air-cooled motor is approximately twice that of the water-cooled motor. These facts are responsible for the crossing of the lines.

10 Of the conditions for efficiency which bear upon this question of fuel weight, and which have led to the selection of the water-cooled

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motor as a type, the first is the compression. The higher the compression the higher the efficiency, and there is no limit until preignition occurs. Statements will be found in textbooks to the effect that there is a limit, but they are the results of mistakes in interpretation, and are erroneous. The amount of compression possible is limited, however, by the metal temperature and by the temperature of the mixture as admitted. Naturally, the warmer the mixture during suction, the sooner it reaches ignition temperature by compression. Therefore suction heating is a limit. Again, the interior metal temperature, if it is high (as it is always), may cause trouble by the contact with the mixture during compression, and some portion of the mixture may be brought to its ignition temperature by hot-wall contact long before the main mass is brought to this ignition temperature by compression alone. It requires only one such hot spot to wreck a well-laid plan.

11 The next factor in efficiency is the mixture quality, and in this there are the following controlling elements: first, mixture proportions. Any excess fuel means direct waste, but it also means carbonization and fouling. Excess air quickly makes the mixture practically non-burnable. Therefore, mixture proportions must be accurately controlled — more accurately than is possible with any existing carburetor. Carburetors are not yet satisfactory, and as soon as satisfactory carburetors are secured from the standpoint of proportionality of the mixture, we may expect to see a further reduction in fuel consumption and more reliable operation.

12 Dryness of mixture is a matter of coördinate importance with mixture proportions. When mixtures are wet, that is, not completely vaporized, the air and fuel cannot be uniformly distributed to the various cylinders by the manifold system. One cylinder will get a different charge from another, as can be easily proved by pressure gages. There are rarely two cylinders alike as to maximum pressures on a multi-cylinder engine using wet mixtures. Drying of the mixture will cure that fault, and also cure the carbonization that comes from the vaporization of the liquid in the presence of the burning gas when it has been admitted to the cylinder in a liquid state.

13 The third factor of the mixture question is homogeneity. However accurately the mixture may be adjusted as to fuel and air ratio, however carefully the mixture may be distributed, cylinder to cylinder, the fact remains that, in order to produce economical results, the charge in any one cylinder must be uniform in every cubic inch of it. It is not sufficient that the right amount of air be in the

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cylinder even if the fuel is vaporized, when the latter is all in one corner.

14 Following mixture quality, the next factor in efficiency is rate of flame propagation with reference to piston speed. It can be shown that the explosion line of the indicator card following compression must be maintained vertical for maximum efficiency. Now, the rate of propagation is the one factor that tends to hold it vertical. If the propagation rate is high enough for a given piston speed, so that the explosion line is vertical, the efficiency will be high. But should the piston speed exceed a certain value, then the explosion line will begin to lean toward the expansion line, until by and by it becomes horizontal and merges into the expansion line, with a consequent large loss of work area and low efficiency or high fuel consumption. Therefore, there is for every given mixture a limiting piston speed that cannot be exceeded without destroying efficiency, and we are now approaching that speed in aeroplane engines.

15 The next related factors are mean effective pressure and speed. These are the prime factors for the output of a cylinder.

16 If the mean effective pressure were constant, then the horsepower with reference to the speed would follow a straight line. The mean effective pressure is not constant as the speed varies, however. Therefore, plotting horsepower against speed gives a curve having the general form of concave downward and consisting of several separate portions, each worthy of study. There is usually a straight portion over a given speed range, during which the mean effective pressure is constant. For lower speeds the mean effective pressure is lower, and for higher speeds the mean effective pressure is again lower. From the point where, with increasing speed, the straight line becomes a concave-downward curve, the mean effective pressure is decreasing as speed increases, until at the point where the tangent to the curve becomes horizontal, the rate of increase of speed is exactly equal to the rate of decrease of mean effective pressure. At a little higher speed mean effective pressure decreases faster than speed increases, and finally the curve drops down toward zero power.

17 So much for the facts. An analytical engineer cannot be content with those facts, however, but finds it necessary, if he is to apply a cure, to go behind the facts to ascertain the reasons. The first step in doing that is to determine the volumetric efficiency of the engine by measuring the air and fuel and comparing the total volume of mixture taken in with the piston displacement. If the volumetric efficiency be plotted against the speed, much light is thrown on the

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situation. In the first place, the volumetric efficiency falls off in the region of very low speed, where the mean effective pressure is low; it is constant over the region of constant mean effective pressure, where the horsepower-speed line is straight, and then at some high speed it again decreases. It is clear, therefore, that curvature of the horsepower-speed line is due to a corresponding variation of volumetric efficiency. It may be found, however, that at some high speed the horsepower-speed line falls before the volumetric efficiency. This calls attention to the fact that the falling-off of mean effective pressure at high speeds may not be due primarily to volumetric efficiency but to other causes, and recognition of this starts a search for those causes.

18 The first of these causes is too slow a combustion, or too high a piston speed. That is to be corrected by adding an additional ignition source, or by moving the spark plug from a side wall to a center point. Igniting at more than one point or at a more central point will cure this defect, and again cause the dropping points of both horsepower-speed and volumetric efficiency-speed curves to lie on the same speed line.

19 Again, it will be found that a change in the valve setting changes this mean-effective-pressure curve at both ends, but every change in the valve setting also changes the mean effective pressure, and the volumetric efficiency is itself the direct measure of whether or not one has the best valve setting.

20 Now, it is curious that most people have played with cams and adjusted them back and forward by guesses, and have never bothered about the air meter, which is the only positive means of arriving at best cam forms and valve timing for sustained mean effective pressure at high speeds.

21 Many more analyses along the above lines could be given, but enough has been said to call attention to this most important means of studying the problem of maximum power at high speed, not only revealing what is the matter but pointing out clearly the direction in which to correct the fault.

22 So much for efficiency and mean effective pressure, or efficiency and horsepower per cubic foot of cylinder. Those two factors bear directly on the fuel weight to be carried and the output per cubic foot of cylinder. What will be the weight of that cubic foot of cylinder? This has to be judged both by qualitative and quantitative analysis. It is impossible to give any quantitative analysis without long mathematical treatment, so I will undertake only the qualitative analysis.

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23 The first point in qualitatively analysing unit metal weight of the multi-cylinder engine is to recognise that the engine can be divided laterally by planes into sections of one cylinder each. The end sections are the same as each other, but are different from the intermediate sections. Therefore, to study qualitatively the relative weights of two typical constructions, the mind must be concentrated upon these sections, each one of which includes a cylinder, a piece of frame, a piece of shaft and the other parts that go with the section.

24 From this point of view, consider multiplication of cylinders in line vs. radially or circumferentially. It will appear that the weight of the cylinder, piston and connecting rod is just the same no matter how the cylinders are arranged, but the frame weight and shaft weight are reduced by any multiplication. It is clear also that, other things being equal, the lighter arrangement is circumferential rather than longitudinal multiplication.

25 Now, going back to the history of the situation, we find every conceivable combination has been tried, but these have finally crystallized to not more than two kinds, giving the V-type engine and the engine with cylinders in line.

26 Considering the effect of cylinder diameter upon unit metal weight, it will appear that from the unit-weight standpoint the cylinder diameter should be as large as possible, because the wall thickness of a cylinder is always greater than necessary for the stress for other structural reasons. A $\frac{1}{16}$-in. cylinder of steel will not be stressed over, say, 10,000 lb. per sq. in. The cylinder could be made much thinner than this and still have a good working stress if there were not other structural objections to it. This being the case, the larger the cylinder for a cubic foot of displacement the less the unit metal weight in the wall, and the only limit to large diameter is good running.

27 Considering the stroke, as this is increased the metal in the cylinder piles up endwise, or axially, too fast with reference to volume, and therefore for minimum unit metal weight the shorter the stroke the better. In proportion, we are using, normally, shorter strokes in aeronautical motors than in automobile engines for that reason.

28 Again, as affecting the metal weight, we have the connecting-rod length. Clearly, the shorter the connecting rod the shorter the frame, and therefore the more metal saved. The only objection to the shorter connecting rod is an excessive angularity, which introduces stresses requiring metal thickening in other places.

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29 The number of cylinders should be as large as possible up to the point where the weight of the connecting parts has to be increased. A 2-cylinder engine has less than twice the weight per cubic foot of displacement than a single cylinder, for the reason that the number of end supports for the shaft, etc., is not increased. Similarly a 3-cylinder has less than three times, a 4-cylinder less than four times, and so on; and the weight per cubic foot of displacement gets less and less until a certain number of cylinders — somewhere about six — is reached where the shaft diameter and the weight of the frame must be increased so as to retain the necessary stiffness, whereupon the saving in weight by multiplication is neutralized. This appears to be about the limit of saving by line multiplication.

30 The metal weight per cubic foot of cylinder displacement has to be taken up along the lines indicated, extending the study to the form vs. weight of each individual member. It will appear, as one examines the forms of these individual members, that one form is clearly susceptible of less weight than another — even with the same working stresses or with equal factors of safety.

31 The first of these studies should be undertaken with reference to cylinders. The first cylinders built were made of cast iron, with head, cylinder and jacket cast in one piece, and the valves being arranged in a side pocket — the ordinary T- or L-head construction. It is clear that the weight of the valve pocket is detrimental. The first step in any cylinder-weight reduction, then, is to take that pocket away, retaining the cast cylinder (on the assumption that we do not know how to make any other kind) and putting the valve in the head. This results in the valve-in-head construction, which is now practically universal, but which, strange to say, it took six or seven years to realize.

32 A similar instance of slow realization of facts exists with reference to the cast-iron jacket wall, which has no other function than to hold water. Cast iron for that purpose, especially in an aeroplane engine, is wasteful of material, so the next step is to get rid of the cast iron. When one stops to think how it is to be done, a structural difficulty becomes apparent, and therefore one must not too readily condemn the holding on to the cast-iron jacket. The difficulty is of course the necessity of providing openings for the intake or outlet from each valve, an igniter plug hole and at least two pipe connections for the jacket, and in an aeronautical engine under heavy stress there is some driving gear which requires fastenings. This naturally tends toward the use of a casting.

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33 Suppose such a casting is used, with inlet and one exhaust valve each with a port leading out, and such valve seating in the head which turns down to form the cylinder; then the casting may be led around the top, forming the enclosure of the head jacket and joining the several outlets and coming down outside the cylinder. The cylinder-head jacket casting ends in the form of a skirt at about the level of the valve deck, and to this end a tube jacket can be added by any one of several possible fastenings. That is the next step: cast iron for the cylinders, head and head jacket in a one-piece casting, but with sheet metal for the jacket over the cylindrical barrel. It is a logical step, but it took several years to reach it just the same.

34 Proceeding along the same line of weight reduction, the next step is to cut away this cast iron joining the ends of the ports and forming the wall of the head jacket, and substitute sheet metal welded to the ports by the oxygen welding system. Wherever there are connections to be made for attachment of gears, there must be some additional supports welded or brazed on. The cast-iron cylinder is still there, and with cast-iron ports.

35 There is a fundamental objection to a cast-iron cylinder for aeronautical work, and it is a perfectly valid one. Cast-iron cylinders do not have to be very thick to be amply strong, so far as the gas-pressure stresses are concerned, but the fact remains that so long as they are cast iron, no one knows whether they are good cast iron inside or not, and the use of cast iron cut down to $\frac{1}{8}$ in. in thickness incurs taking some chances. Hence attention is turned toward steel.

36 Drawn steel or forged steel is a reliable material and a logical selection, so designers have sought means of using it; but when one stops to think how to use a drawn-steel tube for a cylinder, and get the necessary attachments on it, one soon recognizes that the matter is not so easy as it looks. That is the reason the adoption of the steel cylinder was so long delayed.

37 There are now several schemes developed for steel cylinders. The first of these is a steel cylinder of a drawn tube formed without a head, screwed into a separate head carrying the ports and the head jacket cast in one piece. This is rather a satisfactory way of attaching a head, but it involves more than one difficulty. When such a screwed head is set up against the shoulder, it is not at all clear just where it is going to stop; and to secure the proper position one must either scrape the faces or shim them — neither of which is a nice job. A further objection is the considerable weight of the cast iron in a rather complicated casting, and also the inner wall of that cast iron

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is a stress wall, the stress of which must pass through the thread to the cylinder. There is no objection to using a casting if it is not stressed, but a casting under stress is not satisfactory and is to be retained only in the absence of something better.

38 Complete elimination of castings has been tried by using all-steel and sheet metal welded together, but this did not prove satisfactory for a very interesting reason. A flat sheet-metal head on which the valves are seated will not remain flat, and a round valve seat will not stay round. Such sheet metal tends to warp out of shape, and with it the valves will not stay tight. However, the material does not break, which is something worthy of thought.

39 To eliminate the weld between the steel cylinder and head, another construction was developed. In this a seamless drawn-steel shell with head just like a cartridge is used, and two holes are arranged in the head to seat the valves. It is evident that this is a structure which is sound against all kinds of stresses. It still has some of the difficulties of warping the seats, causing leakage of the valves; and when a valve leaks the amount of heat developed is tremendous. Once a valve starts to leak, it is only a question of a short time before it will be completely destroyed.

40 The particular construction of cylinder just described is rather difficult to attach to its jacket ports. It is interesting to note one case at least in which a satisfactory attachment has been worked out, and that is the Hispano-Suiza engine, now used on the European war front, and now also being built in this country. In this particular engine the entire outside of the cylinder is threaded, and the cylinders are screwed into an aluminum casting which is double-walled just like the cast-iron block casting of an automobile engine. The thread performs the double purpose of holding the cylinder in place and bringing its head up against the aluminum cast head which carries the ports, and also acting as a thermal bridge between the metal of the cylinder and the metal of the aluminum casting which carries the jacket water. Without the latter there would be poor thermal contact and overheating of the cylinder. While this construction is not entirely satisfactory, it is nevertheless very interesting and suggestive. It immediately calls attention to the fact that a water jacket may be made of an aluminum casting and the ports formed just as easily as in iron, the steel interior carrying the stress due to the interior gas pressures.

41 It is, however, quite feasible to get rid of the double aluminum wall down along the cylinder barrel into which this steel cylinder is

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placed and which carries the ports above, by leaving out its interior wall and retaining the outside, or even by stopping the wall just below the head as a skirt to take a short thin tube which may itself be of aluminum, ending at the bottom in a cast stuffing-box ring to act as a joint against the steel cylinder. That, so far as I know, represents the last word in this direction, the steel cylinder head being bolted up to the aluminum head-port casting at the valve-seat bases, and not just pressed up against it by a remote thread.

42 Finally, there is to be noted the one-piece steel-forging construction for cylinder, cylinder head, ports and ignition holes, surrounded by a sheet-metal welded jacket, a very satisfactory though expensive construction.

43 These heads are themselves a subject of considerable study. We have first a plain head in which the valve inside diameter is half the cylinder less the width of seat, and half the bridge between the valves. Both valves have stems pointing upward and parallel. The plain cylinder, then, which can be made of a plain seamless-drawn steel cartridge, and which is so desirable structurally, limits valve diameter, and this is a factor against it. Valve diameter is a strong influence in volumetric efficiency and weight of charge, controlling, as it does, flow-resistance conditions. Naturally, designers must get the volumetric efficiency as high as possible by keeping flow resistance as low as possible. Therefore the tendency is to go towards larger valves than is possible with the previous arrangement.

44 One variation in form for this purpose is the flat bulged head where the valve diameter is larger than before by the amount of the bulge. The flat bulged head is a very desirable thing for larger volumetric efficiency and higher mean effective pressure, but offers some difficulty in manufacture when one is making a one-piece seamless-drawn steel job, but not a serious difficulty.

45 Another suggestion for getting the same result is to bulge this head upward in the form of two flats and put the valves on the two inclines. It is perfectly clear that a very large increase in diameter can be secured in this way. The valve stems in this case are not parallel but diverge at any angle and the limit is reached when the angle is 180 degrees, in which case they are horizontal.

46 The question of block arrangement of cylinders and their jackets vs. separate units deserves some attention. In some cases each cylinder with its jacket and head is entirely separate. In other cases the jackets are cast or welded in a block form, around more than one cylinder — sometimes two and sometimes four, and in

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some cases six. It is clear that the more cylinders included in the jacket block, the less will be the weight of the jacket, because the length of the tangent to two jacket circles is less than a half circumference. But there are objections to the block, and in some cases it may not pay to use it.

47 In a case in point, a cast-aluminum block jacket was set down over four steel cylinders which were bolted to the frame by their usual flanges and studs. These cylinders gave trouble on the outer flanges, the end studs breaking off or pulling out. The trouble was caused by the crankcase running hot, expanding, and the aluminum block cylinder casting running cool, because it was water-jacketed, not expanding. The cylinders being bent inward tore the stud ends right out.

48 Another point: the steel cylinder is naturally flexible, and it belongs — in fact, the entire motor belongs — to that class of structures which should properly be termed flexible, exactly similar to bridge structures.

49 These flexible motors weave just as the engine of a steamship weaves. To attempt to hold one against springing is to attempt what is practically impossible. The cylinders of aeroplane engines should all be perfectly free to go as they will, and not be held on the top in any way. All the block arrangements of cylinders of the sort just described are therefore objectionable. Steel cylinders have a natural spring and give to them, and if let alone they will serve well; but attempting to secure them may result in serious distortions, or in highly localized excess stresses.

50 It was my intention to elaborate on the different arrangements of valves and valve gears, but that would take up too much space, so I will first just draw attention to some typical gears. One of these has a rocker arm overhead, worked by a push rod from a camshaft in the crankcase. In some cases this one push rod works two valves. When the valve stems are in line with the rocker fulcrum placed in the middle, each may be worked alternately. This push-and-pull may be secured by a single cam having a plus and a minus face, or by two opposed plus face cams having a plus face with a fork — the second form being far preferable. That particular form of driving the overhead valve by a rocker from a crankcase camshaft is now regarded as old-fashioned, but here is one case where there is something in favor of the old-fashioned. The new fashion is the overhead camshaft, where one camshaft, running along over a whole line of valve stems, will work them directly, or, being offset a little bit, may

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work through rockers, all stems being equidistant from the camshaft. When the two valves for one cylinder are on a line at right angles to the shaft, the camshaft may be placed between them, working with double rockers.

51 The objection to the overhead camshaft is twofold. In the first place, a camshaft mounted on separate cylinder heads exerts a restraint against their free movement. The variance of that camshaft will necessarily cause a stress, and the camshaft will be bent, and it is only a question of time when something will fail — either by wear or breakage. Again, the cam is very close to the valve stem, and the adjustment of timing is very delicate. It is difficult to adjust a valve directly driven by a cam so that it will be accurately timed, and stay timed, when a difference of 0.01 in. means several degrees.

52 The location of the camshaft down in the crankcase, with rods coming up to the rocker arms or levers, allows each cylinder to be entirely free, and does not interfere with its turning in any direction whatever. Also it permits the use of longer levers and a far more accurate adjustment of the timing clearances between the cam and the stem on the long reach rod; but such a reach rod should be either a tension rod or should not be used at all. A push rod in a place like that seems to be fundamentally wrong. Here is a case of a long column of thickness of about half one's little finger, which is, in many cases, opening a valve — an exhaust valve — against an internal pressure of 40 lb. per sq. in., and a diameter of 2 in. or more, and, in addition, overcoming all the inertia of the gear and valve at perhaps 2500 r.p.m. That is not a proper function for a long column, but is a perfectly proper function for a tension rod, or steel wire, and why no one has put a steel wire between the valve stem and camshaft, which will allow the whole structure to go the way it wants to, instead of abandoning the crankcase camshaft, is more than I can see. Of course, the block construction is more favorable to the overhead camshaft but it has not all the advantages.

53 Coming now to the question of valves, everyone knows that it is of no consequence to lift a poppet valve more than one-quarter of its diameter. It is also true that the valve will work better, and the volumetric efficiency and mean effective pressure be better, the larger the diameter of the valve and the smaller the lift. That is, the valve should not approach the quarter-diameter lift. That condition conforms to good principles of gaseous flow.

54 It is also a fact that the timing of the valves on the high speeds in aeroplane engines, when one is desirous of getting the largest

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possible mean effective pressure, is a matter of basic importance. In no case should an inlet valve close sooner than 20 degrees late, and the amount more than 20 degrees late must still be determined experimentally for each machine, because the porting and manifold are different on each machine and no general formula has yet been found. Likewise the exhaust opening must be 45 degrees plus something ahead; the exhaust closing 5 degrees late plus something, etc. The inlet opening is the only period that does not seem to matter.

55 Suppose one had a valve lift of 0.4 in. — which would be reasonable for one of these motors — the valve is supposed to lift 0.4 in. and close again in the open period of the valve, which we may assume is 200 degrees in round numbers. If one examines that 0.4 in. lift and 200 degrees of crank angle, one finds that a variation of 0.01 in. in the lift corresponds to 5 degrees of crank-angle timing effect. It is clear, therefore, that with valve lifts of the order we are dealing with, in facing the problem of accurate timing we are running into a question of very great accuracy of dimensions, where a difference of 0.01 in. in any part between the cam and the valve stem means a difference of 5 degrees in time, and that may mean a loss of 5 per cent in power.

56 A valve is normally made of a quite thin disk with a small-diameter stem joined by a fillet. It sits in a seat supposedly water-cooled. It is a stress member, and is normally designed for stress. Designers talk about Grashof's formulæ for flat plates as the basis for its design, but that has nothing to do with the case.

57 These valves, designed according to this formula, will burn out. If they are designed according to the flat-plate formula they are quite thin, and their stems also — when calculated for compression loads. Consider heat being added to the outside face of that whole disk, and at a rate that is not equaled in any other structure that we have anything to do with. In the case of the exhaust valve there is some heat added on the other side, too, and when the valve opens there is a tremendous increase on the back as is also true when the valve leaks. But excluding that extra heat, and considering only the heat added on the flat of the disk, the valve can attain a steady state of temperature only when the heat is being disposed of at a rate equal to that at which it is received. Where is the heat going to go? How is it going to get out? It is perfectly evident that the problem of keeping the valve cool is entirely a problem of providing for getting the heat out, because there is no control over what comes in. The heat flow is radially inward, then axially upward to a stem bearing.

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After the heat gets up the stem, it turns off through the stem bearing to the water.

58 When it is remembered that the conductivity of a gas film is ever so much less than the conductivity of the metal through which the heat is flowing, and that the same is true of the water which must ultimately receive it, it is perfectly clear that the amount of area in the stem guide must be very large in proportion to the area of this stem circle carrying the heat up to it, and the ratio of one to the other should be based somewhat on the conductivities, with due regard to gas-, oil- and water-film thicknesses. Also, the heat received on the disk must pass through the cylinder of metal constituting the stem.

59 Therefore, the stem thickness must bear a logical relation to the disk face, and the thickness of the face should regularly increase toward the center. If one followed this out, one could easily develop a rational form for valve based not on stresses but on heat flow.

60 The ratio of the conducting area to the heating surface becomes the prime variable, and it is perfectly evident that that ratio ought to be the same all through one piece of metal itself, and ought to be increased when the heat must cross a bridge, as at the stem guide where there is a film of oil or dead gas, by an amount representing the ratio of thermal resistances. If one does that, he is carrying through the principle of establishing a regular temperature gradient from the most distant point; and it only requires one or two experiments in that direction to decide what metal to use, and what shape, and how close it ought to fit, in order that any fixed temperature will not be exceeded at the hottest part. So long as it remains below a red heat a valve is all right, but as soon as it attains a red heat it will first oxidize and warp and then will cause preignition.

61 This thermal study of a valve has not been undertaken by anyone in the shops. It is one of the things that the scientific men are contributing to this problem, but it is now about to be put to practical use. The same situation exists with respect to the piston, as the following shows:

62 The ordinary piston, as built for aeronautical motors, has been a failure; and even in the best motors to-day I venture to say that, next to the exhaust valve, the piston is the source of greatest trouble. I put it before the exhaust valve. I think more accidents and trouble can be traced directly to pistons than any other single part of the engine structure, and yet pistons have been entirely neglected from this thermal standpoint. In the first place, the aeronautical man, in

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starting out to build his aeroplane on the automobile model, had in mind only one thing — to take metal away from every possible place with the idea that the metal was there only for stress purposes and might be taken away as long as the stress did not go above a certain value. What happened? In the first place, the piston was cut off from one and one-half diameters long to less than one diameter long, which reduced the contact between the piston barrel and the cylinder. Not being satisfied with that, the early designer bored holes in the piston and then cut the head down until it was $\frac{1}{8}$ in. in maximum thickness, and frequently only $\frac{1}{16}$ in. across the top. So far as stresses were concerned the piston thus reduced was all right, but it ran hot and soon gave trouble.

63 Consider the piston from the standpoint of heat dissipation, and something surprising follows the logic of the analysis. The piston is receiving heat all over the top at a very high rate. Where is the heat going? It must go out through the barrel walls and the oil film to the cylinder — that is the only place it can go.

64 It is perfectly clear that the heat received within a circle drawn concentrically on the head must pass radially outward through a cylindrical surface equal to the circumference of the circle multiplied by the head thickness at that point. The heat received within a larger circle drawn on the head, passing also radially outward, must have a larger head thickness at its circumference. If the temperature is not to get unduly high, then the head thickness must regularly increase from center outward, so that the metal-conducting area bears a constant ratio to the area of the heat-receiving circle to control the temperature gradient from center to edge. The principle is the same as is used in designing copper electrical conductors to control the voltage drop. It can be shown by a simple equation that the thickness ought to increase on a straight line.

65 When the heat gets to the edge, it is clear that it must flow down the piston barrel. Therefore, there ought to be as much metal behind the first ring as the thickness of the head at the inside edge of the barrel. Practically no heat can get through the ring, this being a floating member. Then the barrel thickness can be regularly decreased toward the open end, to control the temperature gradient from end to end. It is also clear that the more surface there is around the barrel, and the better the fit, the easier it is to establish a low-temperature gradient between piston barrel and cylinder wall, providing there is sufficient conducting metal in the piston walls, head and barrel. From considerations of that character, backed up by any

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number of broken and burnt pistons, it is about time we stopped cutting the metal out of the pistons and began putting in considerably more metal. The additional weight is not going to injure the motor at all, but will permanently have the effect of enabling it to run longer periods of time.

66 A qualitative analysis of frames is also worth while. The frame of the aeronautical motor has been regarded as a thing that nobody has to be bothered about. It was a crankcase and of course we had lots of crankcases. Automobile crankcases had been made in great numbers and variety, and it seemed a simple thing to create an aeronautical-motor crankcase from that of an automobile motor.

67 Now, it is a fundamental fact that if one is going to reduce the metal weight of a structure such as this to a minimum, every piece of metal should be required to carry a very heavy stress — as heavy a stress as possible, and do it all the time. The basic principle, then, of weight reduction, after the thermal considerations have been disposed of and the conditions for high mean effective pressure and thermal efficiency properly met, is to make the metal carry real loads. That is not to be accomplished with the ordinary crankcase construction, because the crankcase is a reasonably heavily stressed member, and is subjected to complicated sets of stresses that cannot be opposed with any economy of metal weight by a common casting of box form — which is all that the ordinary crankcase is.

68 The old-style crankcase, of upper and lower halves, formed a box with holes on top to take the cylinders. The lower half of the box carried webs, which in turn carried the bearings with top caps. If one started off with the idea of designing a structure as little adapted to the stress conditions as possible, this is about what he would get. Consider the fact that the stress due to the gas pressures is always upward, producing tension in the cylinder and its fastening to the frame that is carried out along the flat top of the box as a beam load and down along the upper side walls as tension; then through the parting joint to the lower side walls, and then through the webs as beams from both sides to the main bearing and shaft, where it finally ends. Coming around like that is an excellent example of indirectness of stress transmission and consequent demand for the maximum of metal.

69 Consider also that the crankcase is stressed in another way, in that it has in the 4-cylinder motor a pair of cranks acting downward between a pair acting upward, so that there is a rotating radial centrifugal load due to both rotating masses and the inertia of the

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reciprocating parts. This sort of loading puts on the crankcase the duty of a beam, but in which the direction of loading rotates. It would appear that the box structure is rather better for the beam-load condition than it is for this tension condition.

70 Slowly these ideas have percolated, and the effects are to be seen. The first direct effect is noticed when this bottom web is eliminated, and the bottom crankcase member ceases to be a stressed member, and becomes merely what it ought to be — a cover. The web is introduced in the top half, and the bearing now has bottom bearing caps held by studs in the top web. Now the gas pressure stress can come straight down through the webs. This, however, is not as satisfactory as it might be, because each web is a plate subjected to the same kind of stresses as a truss is. The next suggestion, therefore, is to build it truss-like; and we find top-web castings taking truss forms, cutting out holes in the unstressed section of the web member. That is an example of appreciation of the nature of the problem. The next step, however, shows rather more intelligence, where there is substituted for the cast web member, a high-tension steel long-bolt member running up through a hole in the web. That bolt takes a bearing cap on one end and takes the cylinder flange on the other end. This represents the last word today.

71 It is my belief that the next step should be to eliminate the cast-aluminum webbed box member entirely, and to build the whole thing of direct truss form, using nothing but steel. Furthermore, I do not hesitate to say that it is my belief, founded upon the study of practice and on some analyses, that no member of the aeronautical engine that is subjected to heavy stress should be anything but steel, except when that member is subjected to heat-carrying conditions and must be designed for heat-carrying, rather than stress resistance, in which case it will be found that there is more than enough metal for stress. This leaves only one other class of member, which is the enclosing member and which can be made of whatever suggests itself.

72 So, to my mind, the aeronautical engine is emerging from the stage of invention to the stage of design; as a light, high-tensioned steel structure, consisting of seamless tubing and forged or welded steel parts, possibly formed in drop-forge dies. Add to that steel-stress structure certain members, such as the piston, exhaust valve and guide, designed primarily for heat-flow conditions and not for stresses. Add to that again certain closing members, such as the ports for the intake and exhaust, which can be very properly cast in

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aluminum; and the oil crankcase closure, which can be made of anything you please.

73 Now, in the course of this designing it is necessary to build, test, analyze results and repeat. One can argue, as I have done, at very great length from the standpoint of qualitative analysis; but that sort of analysis, however nicely it leads into certain directions, as shown, does not give the right answer. It requires in addition a quantitative analysis, which can only be obtained experimentally, and which is the final step which we, as engineers, are bound to demand.

DISCUSSION

R. C. CARPENTER (written). Dr. Lucke's paper should be read in connection with a paper by Neil MacCoull, Jr., presented before the Society of Automobile Engineers in June 1915. The two papers are in remarkable harmony on the principles of design which apply, and the possible results which might follow due to the selection of materials.

The particular problems which have made the production of the aeroplane engine more difficult than internal-combustion engines for marine and stationary purposes are, without doubt, due to the important requisites of capacity, reliability, lightness, and efficiency, which requirements are conflicting to a greater or less degree.

The question of reliability involves lubrication, carburation, and all the problems relating to continuous operation. So far as I can recall, there is no other class of engine in which the question of reliability is so vital for results. In the marine or stationary engine, failure of the engine to operate merely requires repairs or adjustments which, although possibly inconvenient, can be made without endangering the entire supporting structure; this obviously is not the case should the aeroplane engine fail to run for any reason.

In both papers steel is recommended as a substitute for cast iron, which is obviously a desirable change so far as the substitution may be practicable, and is already in extensive use. In this connection it would also seem to be of advantage to employ aluminum alloys as far as they prove themselves to be serviceable and reliable, both because of the light weight and of the higher heat-transmission coefficients which such alloys have as compared with cast iron.

It is my opinion that the aeroplane engine is now passing very rapidly through a development period of high refinement, and that a short time only will be required to fully disclose the essential

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requirements as to types, materials, and details of workmanship, which, I believe, will in a general way be of the type described by Dr. Lucke.

O. C. BERRY [1] (written). One of the first points to attract my attention is the importance which the author attaches to motor efficiency and the part which quality of the mixture plays in determining this efficiency. Happily, I am able to support this point with the results of tests carried out in the laboratories of Purdue University for the specific purpose of showing the effect on the performance of a motor of changing the character of the mixture.

In carrying out these tests a Wisconsin motor was used, mounted on a Diehl dynamometer. The air to the carburetor was measured by an Emco meter, which is built like a large tin meter. The temperature of the air entering the carburetor was measured by a mercury and glass thermometer and care was taken to keep this temperature near 100 deg. fahr. The pressure and humidity of the air were also noted. By means of the Diehl dynamometer the speed and power of the engine were accurately measured. The engine was run at a series of different speeds and loads. The carburetor was adjusted to give a good mixture and the throttle set so as to give the desired speed and load. With the throttle held unchanged in this position, the gasoline-and-air mixture was varied in consecutive steps from the leanest with which the engine could run to the richest. The brake load was varied each time until the engine came back to the desired speed. As the amount of mixture drawn into the cylinder per minute was thus kept constant, regardless of the amount it contained, the power developed is a direct indication of how powerful the mixture is. In Fig. 1 the pounds of gasoline per pound of dry air are plotted horizontally and the brake horsepower and per cent thermal efficiency based upon the b.hp. are plotted vertically. The power curve shown is for half load at 1300 r.p.m., and shows how the power varies with the mixture. The vertical line at point 0.0671 represents the theoretically perfect mixture. The efficiency curves are those for half load at 400, 1000, 1300 and 1600 r.p.m., and show how the speed will affect the influence of mixture upon the thermal efficiency. In Fig. 2 the efficiency curves are given for quarter, half, three-quarter and full load at 1000 r.p.m., and show how the load will affect the influence of mixture upon thermal efficiency.

[1] Purdue University, Lafayette, Ind.

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These tests show that the most efficient mixture coincides almost exactly with the theoretically perfect mixture when the engine is running under load, and is considerably leaner than the most powerful

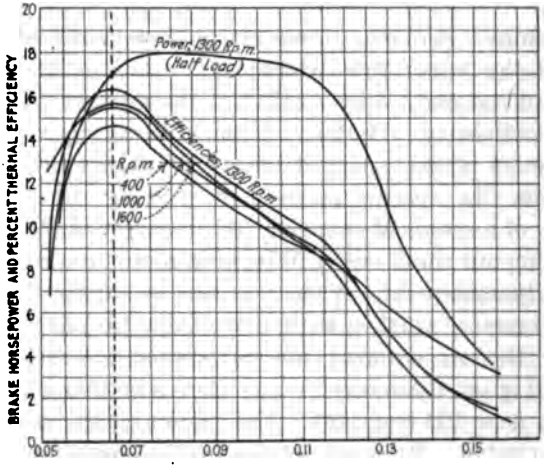

FIG. 1 VARIATION OF ENGINE POWER AND THERMAL EFFICIENCY WITH RICHNESS OF MIXTURE

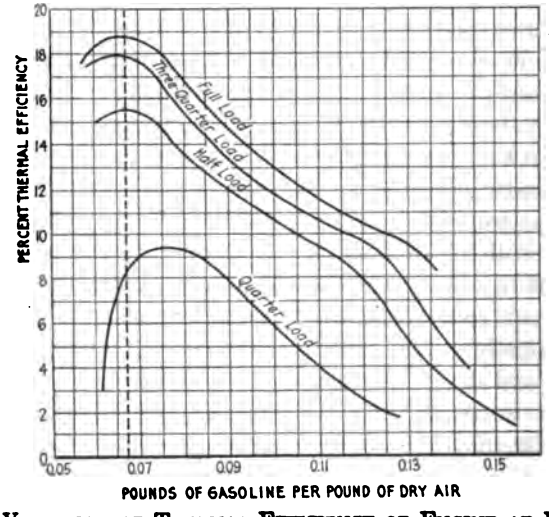

FIG. 2 VARIATION OF THERMAL EFFICIENCY OF ENGINE AT DIFFERENT LOADS WITH RICHNESS OF MIXTURE

mixture. For low-load conditions the richer, more powerful mixture seems to be more efficient as well, probably due to the fact that it fires more regularly at low pressures.

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At first glance it may seem odd that an excess of fuel in the mixture will make it more powerful than a chemically perfect mixture. This may be accounted for, however, by the fact that the hydrogen burns at the expense of the carbon in the richer mixture. How this can increase the power may be understood by the analogy of methane, CH_4, burning in air. One cubic foot of methane will require 9.56 cu. ft. of air to burn it completely and will give up 1072 B.t.u. This same 9.56 cu. ft. of air will burn the hydrogen out of 2 cu. ft. of methane and liberate 1392 B.t.u. Thus the richer mixture, though wasteful, is the more powerful.

The tests also show how very important it is that the mixture be correct if high efficiency is to be obtained. In this connection it is important to note that any change in the temperature of the air or the fuel flowing through the carburetor, or a change in the altitude, will change the character of the mixture furnished by a carburetor having a fixed setting. For this reason the carburetor should be furnished with an adjusting device which can be operated from the driver's seat. By such a means the mixture may be kept correct while the machine is in the air. The rule for the operator to follow will be indicated by the curves in Figs. 1 and 2, and may be stated thus: Make the mixture leaner until the engine loses power, and then make it richer, a little at a time, until the power is restored. The leanest mixture with which the engine will pull satisfactorily is the most efficient.

I can scarcely agree with Professor Lucke that drying the mixture is a sure cure for carbon in the cylinders. A dry mixture may be too rich and cause a heavy carbon deposit, as was indicated in a previous paragraph.

The aeroplane motor, like the racing motor, is designed to do most of its running at a speed and torque which are nearly constant. The best way to speed up the rate of combustion in such a motor is to increase the compression. The racing motors develop their best torque at about the speed at which the aeroplane motor is required to run, and give their best power at nearly twice this speed. The rate of combustion and piston speed are therefore scarcely controlling factors in aeroplane-motor design.

At the present time the factor which limits the speed at which an engine can run continuously at full torque is the ability of the bearing at the lower end of the connecting rod to keep cool enough to permit proper lubrication. This is borne out by the experience of automobile-race drivers. An examination of the experience of sev-

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eral hundred cars entered in various races shows that many more engines fail due to crankshaft and connecting-rod trouble than due to piston trouble, and that valves do not cause half as many failures as crankshafts. To Professor Lucke's list of pistons and valves we must therefore add that the connecting-rod and main bearings on the crankshaft must be designed primarily for heat dissipation. The best way to accomplish this is to supply them with a copious supply of oil under pressure, and thus oil-cool them.

CLAUDE M. GARLAND (written). There are two points in the paper which the writer's experience would indicate to be of first importance, not only in the design of aeroplane engines, but also in the design of all internal-combustion engines of the single-acting type. These are the design of the exhaust valve and the piston from the standpoint of thermal conductivity for the purpose of maintaining the temperature of these parts at such a degree as to prevent preignition of the charge.

The piston is the more difficult member to handle, and in most instances is the principal offender in premature-ignition troubles. This was clearly illustrated in the testing of a single-acting engine which had given the writer considerable trouble from preignition. On removing the plate which carried the spark plug immediately after a test, the piston was found to be at a low-red heat.

Some experiments were made on this engine for the purpose of determining to what extent the temperature of the piston affected the premature ignition. A small nozzle was located in the end of the cylinder and an injection device provided whereby a very fine stream of water was discharged on the piston head on the opening of the exhaust valve. This not only cooled the piston head, but also the exhaust valve and the cylinder walls. In fact, sufficient water was injected to lower the temperature of the exhaust gases to about 500 deg. fahr. Under these conditions illuminating gas, which normally could not be compressed to over 70 lb. without premature ignition, could be compressed to 250 lb. without any trouble whatever from this cause. The maximum pressure of the cycle approached 900 lb. per sq. in. Under these conditions the engine indicated a thermal efficiency approaching that of the Diesel.

While it is not possible to provide water injection for the cooling of an aeroplane engine, yet it is possible, as the author suggests, to minimize greatly the troubles through proper design of piston and valves for the rapid conduction of heat.

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H. L. HORNING (written). Professor Lucke's analyses of the mixture question in Pars. 10–14 are fundamental with any fuel, but become particularly apropos with fuel having end points 400 deg. fahr. and above.

In Par. 16 the conception of the straight portion of the m.e.p. curve is no doubt borne out by the inaccuracies of our testing methods, wherein small variables make it impossible to read slight changes in ordinates which must exist, producing a peak in the curve at some maximum point. It does not appear to be a mathematical probability that we should actually have a straight portion to the curve, which is the resultant of variables of a higher than first degree. Of course, for all practical purposes it may do no harm to consider a portion flat, but for the sake of future deductions it appears more satisfactory to think of the curve as seldom being straight.

The discussion of arrangement of cylinders and jackets in Pars. 46–49 suggests a thermoanalysis of the motor by dividing it horizontally into layers ½ in. in thickness and laying out a curve with the layers as abscissæ and as ordinates temperatures in different horizontal-vertical planes. Such an analysis would open the eyes of most of us to a new realm of design, and would show why valves do not seat and pistons seize with apparently no reason. It would also show how far the crankcase might be brought up on the cylinder, which might be made with separate heads. Block cylinders fail through our lack of knowledge such as this analysis would give.

In Pars. 57–61 there is further evidence of designing from the thermal-stress standpoint. Without desiring to take issue with the author, laboratory investigations show that heat flow is from the center of the valve to the seat and up through the stem, if the area is sufficient. Here comes the question of stem diameter from the standpoint of heat conductivity and not wear. In valves running under high output there is a dark annulus on the outside corresponding to the conductivity of the seat. The wider the seat, if it seats well, the cooler the valve and the wider the annulus; but the wider the seat the greater chance to catch carbon and the lower the effective area for a given lift. These are shop observations which do not seem to check the analysis of the text. A valve head does not always receive the same amount of heat on the outer edge, nor is the water cooling of the seat always uniform on the circumference, all of which causes unusual distortions.

The author's thermal-stress analysis of the piston in Pars. 62–65 is a masterpiece. Attention should be called to the fact that the

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center of the piston head usually gives the trouble and controls largely the cylinder bore for high outputs.

Thermal analysis of the cylinder illustrates the necessity of neglecting the lower regions of the flame-swept bore while giving unusual attention to the regions of the exhaust valve and spark plug. The tendency of this treatment is to bring about a more uniform temperature throughout the cylinder structure.

Pars. 66–70, dealing with the design of the crankcase, are certainly worthy of the attention of all engine designers, both from the thermal and dynamic standpoints. Most crankcases are deplorably weak, even in otherwise well-designed engines.

It seems proper here to accent the tendency so aptly crystallized in this paper of reverting to the fundamental conception of the fact that the internal-combustion engine is a heat engine and must be designed with this primarily in mind before the dynamic designing is done. This course has seldom, if ever, been followed in the past, but is the direction in which real progress must be made.

H. E. Morton (written). The paper states that the ordinary aeronautical-engine piston today is a failure, and is, with the possible exception of the exhaust valve, a source of greatest trouble. While this may be true of some engines, I have for several years been having absolutely no trouble with pistons, and especially those of the aluminum variety. The problem of heat conduction through the piston is unquestionably of great importance, but I find that it is a comparatively simple matter to design a strong, light and also cool-running piston for even comparatively high-speed engines.

It is interesting to note the reference in Par. 52 to the use of wire for actuating the valves. I suppose that is one of the first suggestions that comes to the mind of a designer, but my experience has been that to incorporate neatly such a member is not a simple matter.

It seems that Professor Lucke, for some reason or other, has omitted to mention the detachable-head design, which is apparently growing in favor in aeronautical work. This design is certainly most convenient both in manufacture and field work, and is especially applicable in connection with aluminum cylinder jackets. The method mentioned in Par. 40 is more or less expensive and troublesome, and a much simpler method can be resorted to where a detachable head is used. Aluminum heads with cast-iron valve seats are proving very satisfactory, and with a light steel sleeve shrunk

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into an aluminum casting this detachable-head design becomes extremely lightweight and accessible.

E. W. ROBERTS[1] (written). The air-cooled motor is still a considerable factor in the aeroplane, and for certain classes of machines, like the fast scout, is still in considerable favor. So far as the 2-cycle engine giving way to the 4-cycle type is concerned, this would warrant the assumption that the 2-cycle was the original engine. The majority of the 2-cycle engines that have been offered for aeroplanes have been poorly constructed and poorly designed. The trouble with this type of engine is not so much with the type itself, but with the builders. It offers a solution of one of the most annoying problems of the aeroplane engine, the trouble with the valves. From 24 to 25 hours of cumulative flying is about all that can be depended upon from the 4-cycle aeroplane engine; it then has to be overhauled, the valves reground and all adjustments remade. This phase of the problem has been prominent since the beginning of aviation. Lubrication has been fairly well solved in the 4-cycle type, but in a rather complicated manner. Valve trouble in the 2-cycle is eliminated because there are no valves. Lubrication of the 2-cycle is simplicity itself because the oil is mixed with the gasoline. In actual flying the 2-cycle has proved itself fully equal to the 4-cycle in all points but one, and that is fuel economy. This is a very important point, but if the same attention is given to the 2-cycle development that has been given to the 4-cycle, this part of the problem will be solved. As it is, the 2-cycle water-cooled motor does not use quite as much fuel as the air-cooled 4-cycle for the same amount of power.

In the problem of carburation two conflicting phases are encountered. One is, we must heat the mixture to get perfect proportions, especially with modern fuels, and heating the mixture reduces volumetric efficiency. Internal-combustion engineers do not altogether agree with the statement in Par. 14 that the explosion line on the indicator card must be maintained vertically for a maximum efficiency. Some engineers seem to think that if the explosion line does not bend toward the expansion line, a certain amount of back pressure will be obtained that will cut down the efficiency. Personally, I have never seen any data to prove this.

In the statement in Par. 17 that curvature of the horsepower-speed line is due to a corresponding variation of volumetric efficiency,

[1] Consulting Engineer and Editor, *The Gas Engine Magazine*, Cincinnati, Ohio.

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and also that at some high speed the horsepower-speed line falls before the volumetric efficiency, I would point out that the two factors of inertia effect of reciprocating parts and vibration in mass have considerable bearing on high-speed efficiency.

Regarding connecting-rod length, Par. 28, I have found the limit in practice is 1.8 times the stroke. While this will undoubtedly appear quite short to some engineers, it apparently gives good results.

Referring to Par. 35, I have used quite a number of $\frac{1}{8}$-in.-thick cast-iron cylinders for aeroplane motors, and have never had any trouble with them. There are several references in the paper to the use of aluminum for water jackets, and apparently for the combustion space. As a matter of interest, I might say that I have built something like 100 aeroplane engines with aluminum-alloy cylinders, and found that when making very extended flights with inadequate radiators these cylinders would break through in the combustion space. In all other respects they gave very satisfactory results.

Regarding valves, and particularly valves in the head, as discussed in Par. 43 *et seq.*, I would like to point out that quite a number of engines have been made with a single valve opening into the cylinder, which would admit of a very large area. There are several ways in which a single valve opening can be employed.

The use of a compression rod (Par. 52) for valve openings is undoubtedly not theoretically correct, but it is giving good satisfaction in practice. The use of a tension rod or steel wire as suggested does not prove so attractive after the necessary mechanism is laid out.

Regarding valve timing, Par. 54, for high-speed engines I have closed the inlet valve as late as 45 deg. past the outer dead center. The best test of the inlet valve is the "flow back." A good plan is to set the valve closing so late that a slight "flow back" from the carburetor will be manifest, and then reduce the lap just a few degrees.

In the matter of valve lifts, an increase in the number of valves permits reduction of lift and reduces both the pounding and the inertia of the mechanism.

In his thermal analysis of the valve, Par. 57, the author has undoubtedly overlooked the flow of heat from the valve head to the seat. The exhaust valve is on its seat about two-thirds of the time, and experience has shown that if the seat is not cooled, valve trouble is encountered.

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A misconception has existed among designers regarding the two functions of the piston. Professor Lucke points out the heat conduction. Another thing is the wearing surface. Short pistons and shuttle-shaped pistons — pistons with the bearing only on the ends — have insufficient bearing surface, which results in rapid wear and a piston slap early in the life of the engine.

A heavy piston is a very bad feature in a high-speed engine. We must keep our piston weights down to reduce the inertia effect. This is very essential.

Regarding the bolts for the cylinders, Par. 68, in my first aeroplane-engine design, made in 1910, I used long cylinder bolts passing through and beyond the crankshaft bearings.

A feature of aeroplane-engine design that appears to be overlooked by quite a number of designers is the crankshaft. There are two factors in this connection which are of great importance and are yet quite frequently neglected. One is the length of the crankpin bearing and the other the securing of lightness by using a hollow shaft. To replace a solid shaft $1\frac{5}{8}$ in. in diameter, I used a shaft $2\frac{1}{2}$ in. in diameter with a $2\frac{1}{4}$-in. hole. This not only decreased the weight to such an extent that a four-cylinder shaft $40\frac{1}{2}$ in. long weighed only $17\frac{1}{2}$ lb. when finished, but the large diameter of bearing reduced the oil-film pressure and practically eliminated overheating in these bearings.

Professor Berry in his discussion states that the motor should be run at the weakest mixture at which it can operate. This, if done, would result in heating the motor and blowing off the radiator.

H. M. CRANE [1] (written). The service required of an aeroplane motor is so different from that required of a motor-car motor that the design must be radically different in a great many respects, although the underlying principles are naturally the same.

The one supreme requirement of the aeroplane motor is that it shall have the lowest possible weight per horsepower of continuous duty. The weight must include not only the motor and its ordinary accessories, but also the fuel and oil required for the length of flight desired. The limit of power that can be successfully used in aeroplanes has not yet been nearly reached, but already even the lower-powered machines have motors more powerful than all but a few motor cars, while the other military types of aeroplanes employ motors of a power entirely unnecessary in any motor-car service.

[1] Vice-President, Simplex Automobile Co., New Brunswick, N. J.

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The bulk of aeroplane motors will have piston displacements of 500 cu. in. or over, while there are very few car motors as large as 500, the average being from 300 to 400.

Not only must an aeroplane motor be able to operate continuously at full load without distress due to overheating or other troubles, but it must also have as nearly as possible 100 per cent of reliability. This latter requirement is always present, due to the danger involved in a forced landing at some place unfavorable to landing. It does not have to be particularly quiet, in view of the very considerable propeller noise. A very moderate amount of muffling of the exhaust and practically no attention to mechanical quietness will meet all the requirements.

Extremely long life in hours of operation, without repair, has not yet been required of aeroplane motors, although the time will undoubtedly come when this feature must be given more serious consideration.

Flexibility, as we know it in the motor car, is not required in an aeroplane power plant.

In motor-car work, light weight of the power plant, while of considerable importance, must still be sacrificed to a number of other important requirements, such as quietness, absence of vibration, long life, and cheapness of construction. The average speed of touring-car motors is much lower than the speed of aeroplane motors, while a wide-open throttle is a rare occurrence for more than a few minutes at a time. The speed of truck motors is higher on an average than that of touring-car motors, but even that does not approach the speeds now in daily use in aeroplane motors. Flexibility in touring-car motors is of the highest importance, meaning a very wide range of speeds under wide-open throttle. A touring-car motor also must be as free as possible from vibration. Absence of vibration is also of importance in aeroplane motors, but as only one full-load speed has to be provided for, the problem is considerably simpler than in motor-car motors.

The features of design which bring out the characteristics required may be briefly summarized as follows:

In the aeroplane motor the lightest possible materials are used, aluminum alloys and the higher grades of alloy steel being very largely employed; cast iron, which has given such valuable service in the gas-engine field, is out of the question on account of its weight. The design, as a whole, should be compact, and the number of parts as small as possible. Only in this way can light weight be obtained

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with the necessary strength and stiffness. We therefore see many motors of the V-type or of the radial type, such as the rotating air-cooled motors and the stationary Salmson motor. Block casting of the cylinders where possible is also a great help toward stiffness with light weight.

Efficiency in gasoline economy being so important, as well as power with light weight, the highest possible compression is employed, while valve-in-head motors are almost universally used. Valve timing, inlet pipes and carburetors are laid out with a view to the best possible operation at the full-load speed desired. Ignition systems of only the highest quality are required to furnish the necessary reliability, in view of the high speeds, high compressions, and continued high temperatures. Magnetos are subject to continuous heavy vibration and must be built accordingly, while spark plugs have to meet conditions of high temperature and oil that are rarely present in automobile work. At the present time, reliability of operation requires complete duplicate ignition systems. Complete oil circulation under high pressure, with special means for cooling the oil, is required to take care of the lubrication under the severe conditions imposed.

In motor-car engines, while there has been a tendency toward an increased use of aluminum to reduce weight, cast iron is almost universally used for cylinders and largely for pistons. In many motors the upper half of the crankcase is also made of cast iron.

Valve-in-the-head motors are fairly common, but the greater simplicity of the L-head type, together with its greater ease of lubrication and protection against dirt, has continued it in very general use. Very moderate compression is a general rule on account of the high flexibility required, and for the same reason compromised valve timing is necessary. Carburetors also of a more complicated construction are in very general use. There are many devices in use on different motors, such as chain drive to the different shafts, vibration dampers, etc., which increase the weight but give smoother and quieter operation. Very heavy crankshafts are common, the bearings are heavy, and most of the bolts and nuts are much bigger than required from the point of view of strength alone.

In closing, it might be of interest to consider the question of aviation motors driving propellers direct and those driving them through gears.

The fundamental basis of power in a gasoline motor is, of course, piston displacement. There is, therefore, always the incentive to

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increase the number of revolutions, with the idea of getting the greatest possible amount of power out of a given size of cylinder. We are, however, considerably limited in the possibilities of power increase by increased speed, due to the fact that the power can only be expected to increase in proportion to the speed, while the stresses in many of the parts increase as the square of the speed. Furthermore, as the life of many parts subject to repeated stresses limits the reliable life of the motor, increased speed imposes other difficulties of design.

The principal reason for gear-driven propellers is, of course, the well-known limitation of propeller design, based on the speed of the aeroplane. This limitation in aviation work is exactly similar to the limitation in motor-boat work, which has resulted in many high-speed hydroplanes having propellers geared to run at greater speeds than the driving motors. In aeroplane work the improvement in motor design has tended to outstrip the possibilities of the propeller to such an extent that desirable aviation-propeller speeds are uniformly lower than possible aviation-motor speeds, except in very high-speed machines or in certain types of motor. This is especially true because of the military development of aviation, which naturally places efficiency of operation ahead of long life.

The great advantage of the direct-drive machine from the point of view of design lies in the use of the crankshaft as a propeller shaft also, a manifest economy in material both in the shafts themselves and in the bearings required.

All the studies that I have made indicate that a geared motor must weigh from 15 to 25 per cent more than a lower-speed ungeared motor of the same piston displacement. The question is whether we can get a corresponding increase in horsepower to offset the increased weight. Personally, I think the question is still a very open one; so open, in fact, that I expect to see both types of motor continued in use for some years to come.

THE AUTHOR, to whom the foregoing discussion was submitted, wrote that there was practically nothing for him to say in reply except that he was pleased at the acceptance of the main ideas set forth in his paper and which are concerned with the establishment of rational bases for design, some parts being designed for heat conduction primarily and others for different aims, such as stress resistance. In no case should a single criterion apply to all elements, — nor the same to each, — as the controlling factor in its design.

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No. 1594

TEST OF A MOTOR FIRE ENGINE

By Horace Judd, Columbus, Ohio
Member of the Society

The paper contains the results of a test of a Seagrave motor fire engine having a 4-cycle, water-cooled, six-cylinder motor, 5¾ in. cylinder bore by 6½ in. stroke, 79.3 hp. by A.L.A.M. rating. The motor operated a four-stage centrifugal pump with balanced end thrust.

The maximum capacity was found to be 745 gal. per min. at 122 lb. pressure at discharge of pump, with 2-in. smooth nozzle and 250-ft. hose line with Siamese union. Gasoline used per hour, 0.218 gal. per hp. at rated load.

With coal at $2 per ton (2000 lb.) and gasoline at 25 cents per gal., the cost of producing a fire stream with the motor fire engine is four times that with a steamer. As compared with the horse-drawn engine the motor engine can reach a fire in half the time, is readily converted from locomobile to pumping engine, is more easily and economically operated, and eliminates entirely the expense of maintaining horses for transportation. Its duty is nearly six times that of a steamer.

DURING the past ten years the city of Columbus, Ohio, has remodeled many of its horse-propelled steam fire engines and equipped them with motor-driven trucks so that now more than 70 per cent are motor-driven. The city also has two complete combination gasoline motor-driven and pumping units. One of these combination units, put into service in April 1916, was loaned to the Ohio State University through the courtesy of the Columbus Fire Department for a more extended test than could be undertaken during the acceptance trials by the Inspection Bureau.

2 In view of the importance and value of the motor-driven engine in getting under way and reaching the fire, as well as the ability to change the motor instantly from propulsion to pumping, the writer has been prompted to offer the results of a performance test on this motor fire engine to those interested in fire prevention.[1]

[1] This paper is based on the results embodied in the thesis work of Messrs. E. W. Leatherman, H. V. Walborn, and E. R. Wilson, graduates in Mechanical Engineering, Ohio State University, Class of 1916.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of The American Society of Mechanical Engineers.

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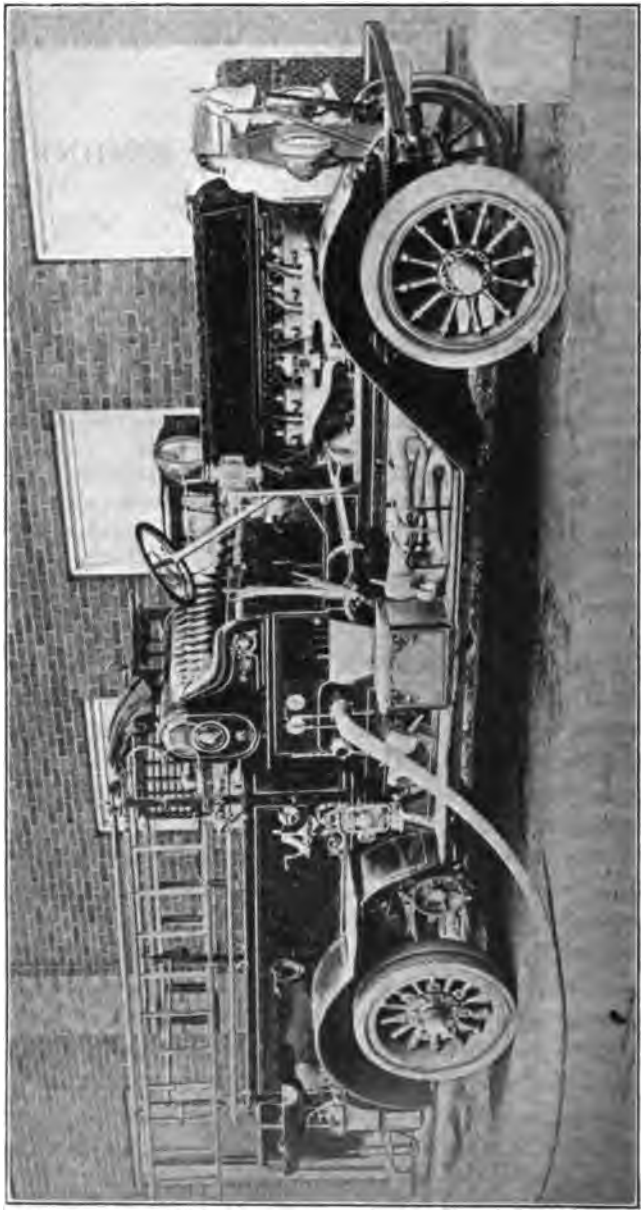

FIG. 1 THE MOTOR FIRE ENGINE

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3 *The motor fire-engine unit* was manufactured by the Seagrave Company, Columbus, Ohio, and consists of a motor-driven, direct-connected, centrifugal pumping unit combined with a hose truck. (Fig. 1.)

4 The motor is a 4-cycle, water-cooled, six-cylinder motor, 79.3 hp., A.L.A.M. rating, and of rugged construction to meet the requirements of fire service. The cylinders are vertical, T-head, cast separately, with integral water jackets. Cylinder bore is 5.75 in.; stroke, 6.5 in. The crank case is parted horizontally through the plane of the crankshaft, the upper section supporting the cylinders and crankshaft bearings and the lower section easily removable and forming a reservoir for oil. There are two camshafts, one on each side of the motor, with the cam gears located in the forward end, encased but easily accessible. The intake and exhaust valves are 2.625 in. in diameter with $\frac{1}{3}\frac{3}{2}$ in. lift.

5 Forced-feed lubrication is used. The cooling water is supplied by a separate centrifugal pump operated from the camshaft. The carburetor is of the float-feed type with automatic auxiliary air intake and is controlled by the throttle lever. The ignition is of double type: (*a*) Bosch high-tension waterproof magneto for one set of spark plugs, (*b*) current from a storage battery through a timer to the second set of spark plugs.

6 *The centrifugal pump* (Fig. 2) is a 4-stage (two stages for each impeller) turbine pump mounted under the driver's seat about midway between the front and rear axles. The casing is of bronze and includes in one piece the guide, or diffuser, vanes, and the water passages connecting the successive stages. The two bronze impellers are mounted on a hollow steel shaft which fits over the drive shaft to the differential and is driven by hardened-steel gears which can be thrown out of mesh when the engine is on the road.

7 Each impeller has 12 vanes 1 in. wide and $\frac{9}{16}$ in. net depth of water passage between the vanes. There are six diffuser vanes surrounding each impeller. (Fig. 3.) The water entering at the center of the pump (Fig. 2) passes into the first stage on the inner half of one propeller, is thrown out by centrifugal force through the diffuser vanes and, passing around the impeller through the water passage, enters the second stage on the other side of the same impeller. From the second stage it enters the third stage on the inner side of the second impeller and is discharged into the other side of the impeller (fourth stage) and from thence it passes into the discharge line. Since the water enters both impellers on the inner side the end

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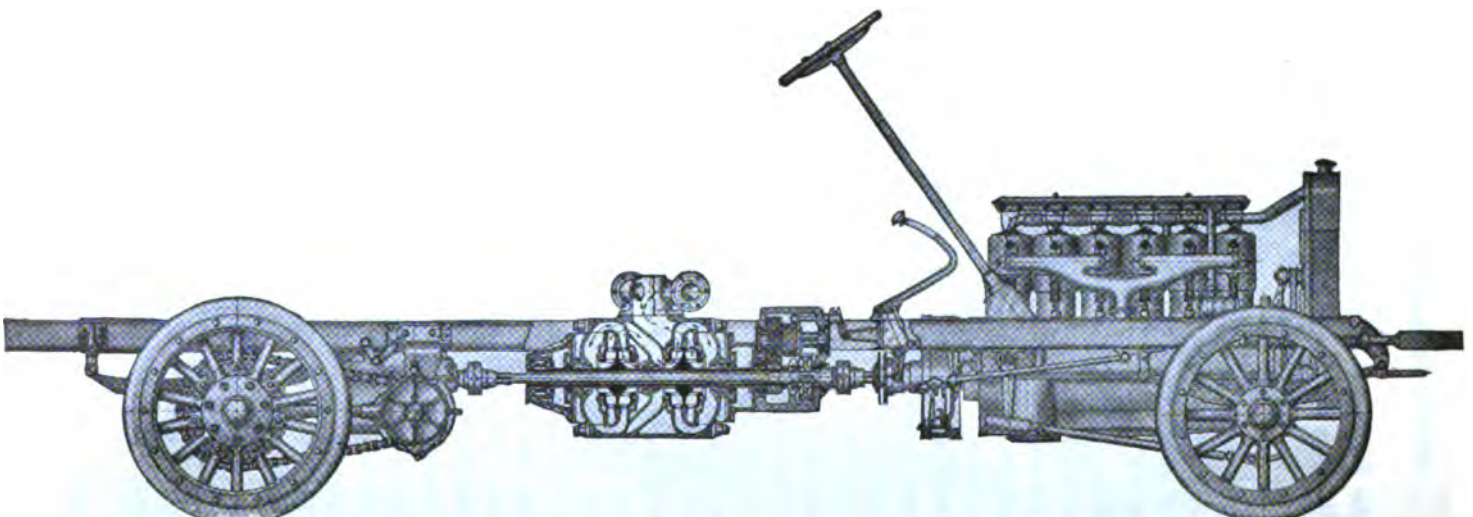

FIG. 2 SIDE VIEW OF CENTRIFUGAL-PUMP CHASSIS

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thrust is practically eliminated, although end-thrust shaft bearings are also provided. Two suction connections and three discharge connections are provided.

8 When necessary the pump may be primed by means of a rotary vacuum pump which will exhaust the air and enable the pump to be put into operation in about 20 sec.

9 The speed ratio of the pump and engine is 2.06 to 1. The speed range of the motor during the tests was about 800 to 1100, corresponding to a speed range of the pump of about 1650 to 2270 r.p.m.

10 The rated capacity of the pump is 750 gal. per min. at 120 lb. net pressure at the pump discharge.

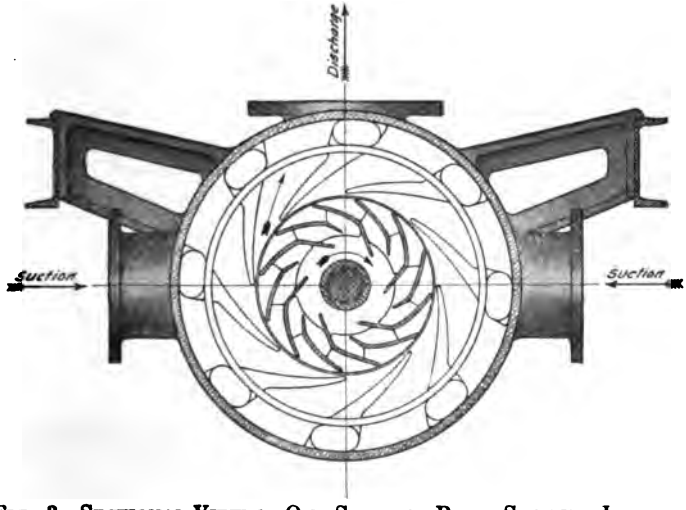

FIG. 3 SECTIONAL VIEW OF ONE STAGE OF PUMP, SHOWING IMPELLER AND DIFFUSION VANES

11 The fire engine under question had come up to the conditions imposed by the acceptance tests, but the city desired further information as to its operation under the management and control of the regular engine men and as far as possible under the usual pumping pressures and fire-stream conditions as met in actual service. *Hence the purpose of the tests* may be outlined as being to determine:

a The capacities of the fire engine when working against the usual range of pressures and with such sizes of fire nozzles as are commonly used

b The fuel consumption of the engine.

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EQUIPMENT FOR TESTING

12 Such a series of tests required the accurate measurement of the fuel used, the water pumped, and the pressures maintained at engine and nozzle.

13 The tests were carried on in the hydraulic laboratory of the University, where the water was taken from one of the large cisterns, or bays, 25,000 gal. capacity, as shown in Fig. 4, through three lengths of 5-inch standard rubber suction hose, and was discharged through the desired length of hose line, first into a series of tumbling bays and finally into the suction bay after passing through an 8 in. by 20 in. standardized rectangular weir.

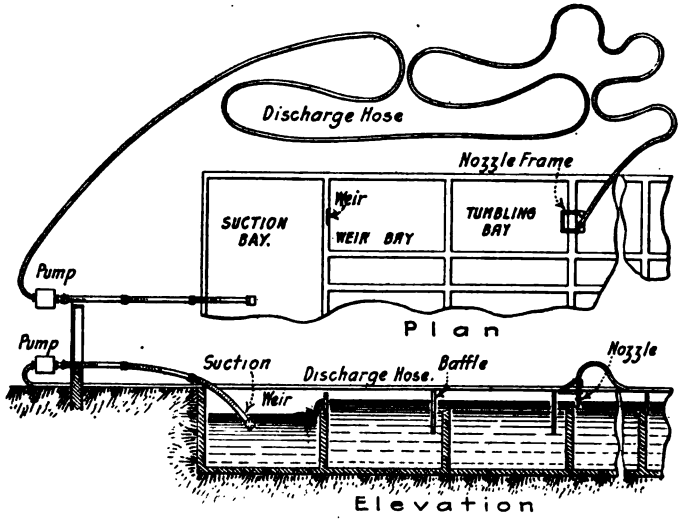

FIG. 4 ARRANGEMENT OF APPARATUS

14 The discharge of the nozzles was also read at the jet by means of the pitot gage, or piezometer, now widely used in fire-service work to give instantaneous readings of the nozzle discharge.

15 The gasoline used was weighed on carefully calibrated platform scales.

16 The pressures at the engines were taken by the regular service gages and their readings corrected for error.

17 The pressure drop in the hose line was taken by means of a specially constructed ring connection for the pressure gage which was located at the hose coupling as shown at *A* in Fig. 5.

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18 The discharge hose was taken from the city service and had seen considerable use but was in fair condition. It was rubber-

FIG. 5 FIRE STREAM FROM TWO-HOSE SIAMESE UNION

lined cotton hose with nominal diameter 2.5 in. and average actual diameter $2\frac{1}{16}$ in.

FIG. 6 PLAY PIPES AND SMOOTH NOZZLES

19 The smooth conical nozzles, shown in Fig. 6, were taken from the regular equipment of the engines. The sizes chosen were those most commonly used in the city fire service.

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TABLE 1 AVERAGE DATA AND RESULTS FOR MOTOR FIRE ENGINE, COLUMBUS FIRE DEPARTMENT, COLUMBUS, OHIO

DIAMETER CYLINDER, 5.75 IN.; NO. CYLINDERS, 6; DIAMETER OF HOSE, 2.69 IN.; STROKE, 6.5 IN.; NO. OF CYCLES, 4; A.L.A.M. RATING, 79.3; GASOLINE, 59.8 DEG., BAUMÉ, 19,000 B.T.U. PER LB.

Item	Siamese connections			Two 1.25 in. on single lines. d=1.246 in. Area=0.00847 sq. ft.			One 1.125 in. on 500-ft. line. d=1.121 in. Area=0.00685 sq. ft.			One 1.25 in. on 500-ft. line. d=1.246 in. Area=0.00847 sq. ft.			One 1.375 in. on 500-ft. line. d=1.37 in. Area=0.01024 sq. ft.		
	1.5 in.	1.75 in.	2.0 in.												
1 Number of run	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2 Revolutions per minute; engine	981	954	966	812	884	969	772	1,000	1,132	770	995	1,116	768	997	1,096
3 Revolutions per minute; pump	2,020	1,965	1,990	1,674	1,820	1,995	1,590	2,060	2,335	1,586	2,047	2,300	1,582	2,055	2,258
4 Suction by gage, ft.	14.84	15.88	18.7	15.88	17.23	19.05	7.93	9.75	11.32	7.48	10.43	12.48	7.93	10.78	11.68
5 Suction by gage, lb	6.43	6.88	8.09	6.88	7.46	8.25	3.43	4.22	4.90	3.24	4.52	5.40	3.44	4.67	5.06
6 Suction (measured) ft.	5.25 (equals 2.27 lb.)														
7 Discharge pressure, lb	157.3	133.5	121.9	95.0	113.0	134.0	117.0	197.4	249.6	116.7	193.5	242.0	115.7	196.0	236.2
8 Discharge head, ft.	363.5	308.0	281.7	219.2	261.0	309.3	270.0	455.0	575.0	269.0	447.0	558.5	266.5	452.0	544.5
9 Total head, ft.	378.3	323.9	300.4	235.1	278.2	328.4	277.9	464.8	586.3	276.5	457.4	571.0	274.4	462.8	556.2
10 Total head, lb	163.8	140.2	130.1	101.8	120.4	142.2	120.3	201.2	253.8	119.7	198.0	247.2	118.7	200.3	240.8
11 Static pressure at nozzle, lb.[1]	95.5	62.3	45.5	44.0	51.9	61.5	51.5	85.0	106.8	40.0	58.2	69.3	35.0	47.5	56.5
12 Static head at nozzle, ft.	220.8	144.0	105.2	101.7	120.0	142.1	118.8	196.0	246.0	92.3	134.0	159.6	80.7	109.5	130.2
13 Length of hose lines (2.5 in.)	Two 250 ft.			Two 250 ft.			One 500 ft.			One 500 ft.			One 500 ft.		
14 Drop in pressure in one 2.5-in. line, lb.	61.8	71.2	76 4	51.0	61.1	72.5	65.5	112.4	142.8	76.7	135.3	172.7	80.7	148.5	179.7
15 Drop in pressure per 100 ft. one 2.5-in. line, lb.	24.7	28.3	30.3	20.2	24.3	28.4	13.0	22.3	28.4	15.2	26.9	34.3	16.2	29.5	35.5
16 Gallons per minute	637	693	745	620	686	720	246	322	360	264	335	383	275	363	399
17 Cubic feet per minute	85.2	92.6	99.6	82.8	85.1	96.2	32.9	43.1	48.2	35.3	44.8	51.2	36.8	48.5	52.9
18 Pitot gage reading, lb	94.9	61.25	43.3	45.6	56.5	64.5	48.5	81.5	105.0	35.0	57.5	71.5	29.0	46.8	57.3
19 Gal. per min. from pitot reading	656.0	718.0	788.0	624.0	699.0	747.0	262.0	340.0	384.0	275.0	353.0	393.0	303.0	384.0	425.0
20 Water horsepower of pump	60.7	56.8	56.7	36.8	44.8	59.6	17.4	37.8	53.2	18.5	38.8	55.3	18.6	42.4	55.7
21 Theoretical velocity at nozzle, ft.	.....	.....	.....	83.4	90.7	98.6	89.3	114.5	128.4	79.5	95.8	104.6	75.0	87.95	95.9
22 Actual velocity at nozzle, ft.	.....	.....	.....	81.5	83.7	94.7	80.1	104.9	117.0	69.4	88	100.8	60.2	78.9	86.1
23 Coeff. discharge of nozzle (including play pipe), per cent	.....	.....	.....	97.5	92.4	96.0	90.0	91.4	91.2	87.2	91.9	96.6	83.0	89.7	89.6
24 Coeff. discharge of nozzle (by pitot gage)	97	96.6	94.5	99.0	91.0	96.3	94.0	94.6	93.6	92.7	94.9	97.6	90.8	94.5	94.0
25 Gasoline per hour, lb	86.9	80.0	75.7	52.4	57.5	73.4	30.8	46.6	81.0	35.5	58.2	80.1	31.6	53.0	95.8
26 Gasoline per hour, gal.	14.0	13.0	12.3	8.51	9.34	11.92	5.00	7.57	13.16	5.76	9.45	13.01	5.14	8.45	15.56
27 Gasoline per hour per water hp., gal.	0.231	0.229	0.217	0.231	0.208	0.20	0.287	0.20	0.247	0.306	0.243	0.236	0.276	0.199	0.277
28 B.t.u. per hour per water hp.	27,020	26,780	25,300	27,020	24,350	23,400	33,580	23,400	28,900	35,800	28,430	27,600	32,260	23,280	32,400
29 Duty per 1,000,000 B.t.u., million ft-lb.	73.25	73.95	73.0	73.28	81.3	84.6	58.96	84.6	66.50	55.30	69.65	71.75	61.37	85.06	61.13

[1] For Siamese connection this gage is located at end of 2.5-in. hose, 12 ft. from nozzle

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PROCEDURE

20 *During the test* the pump was quickly brought up to running conditions and with a full gasoline tank the runs were started and continued for 30 minutes for the runs with double line using Siamese hose connection, and for 20 minutes for the runs using single hose lines. At the completion of the runs the engine was stopped at the instant and the gasoline tank refilled, the amount put in taken as the equivalent of the amount used.

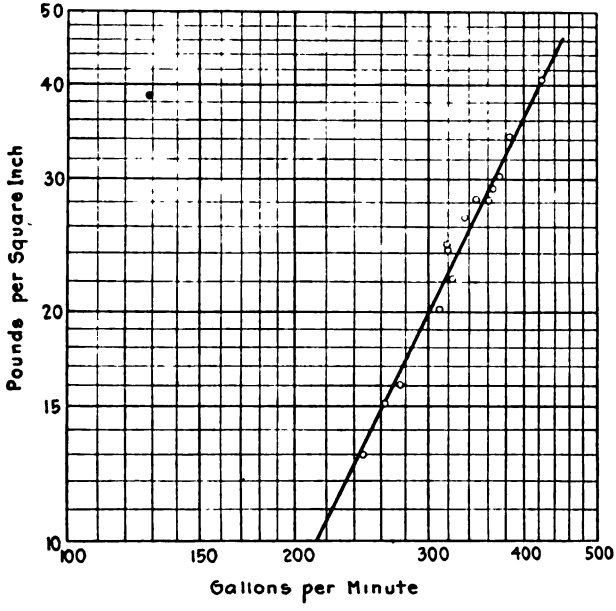

FIG. 7 LOSS IN PRESSURE PER 100 FT. 2.5-IN. RUBBER-LINED COTTON FIRE HOSE

21 The Siamese hose union was a 4-hose connection, but in this case was connected to the pump with but two 250-ft. lengths of 2.5-in. hose. To the Siamese union was attached the 12-ft. length of 3.5-in. hose with the play pipe and the 1.5 in., 1.75-in., and 2-in. smooth nozzles. Single-hose lines, both 250- and 500-ft. lengths, were used with 1.125-in., 1.25-in., and 1.375-in. nozzles. The range of discharge pressure carried at the pump was from 95 to 250 lb.

22 Readings were taken for the whole run of the gasoline used, every five minutes of discharge pressure at the pump, the revolutions of the motor, the pressure drop in the line, and every minute and a half of the weir readings.

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DATA AND RESULTS

23 The average values for *the observed data and the calculated results* from these data will be found in Table 1.

24 Attention is also called to *the principal results as represented graphically on the curve sheets.*

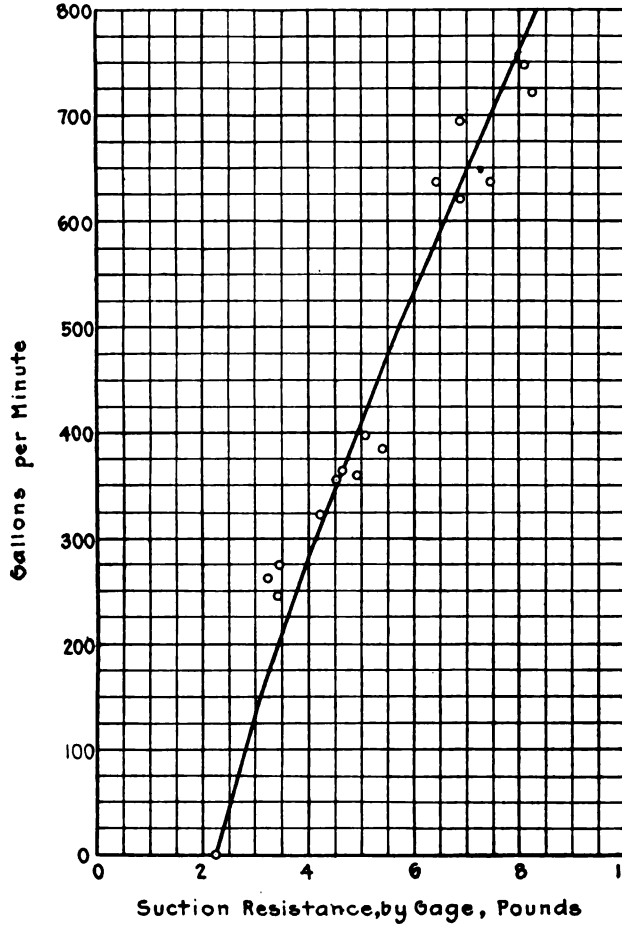

FIG. 8 SUCTION RESISTANCE BY GAGE, POUNDS

25 Fig. 7 shows *loss in pressure* in pounds per square inch per 100 ft. of 2.5-in. fire hose due to frictional resistance to the flow of water.

26 Fig. 8 shows the *variable resistance in the suction hose* as

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shown by the pump-suction gage, due both to the actual vertical lift of the water and to the frictional resistance in the hose, with varying quantities of water pumped.

27 Fig. 9 *is a chart from which the output of the pump in water horsepower can be read* for any given discharge in gallons per minute and total pressure at the pump.

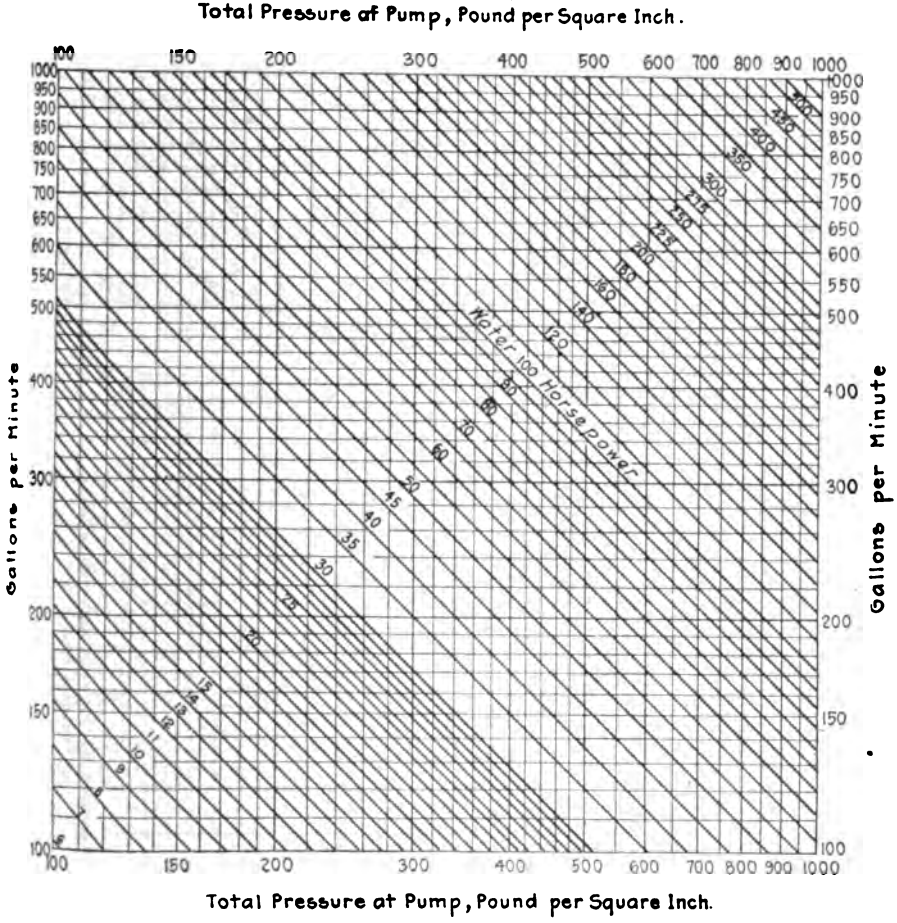

FIG. 9 WATER-HORSEPOWER CHART. WATER HP. = 0.000583 *GP*.

28 The total pressure in this case, where water is drafted, or lifted, from a lower level, is taken as the *sum* of the suction and discharge pressures at the pump. in pounds per square inch. If the water should enter the pump under pressure, the total pressure would

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be taken as the *difference* of the suction and discharge pressures. If the total pressure is below 100 lb., the upper part of the chart should be used and the results divided by 10.

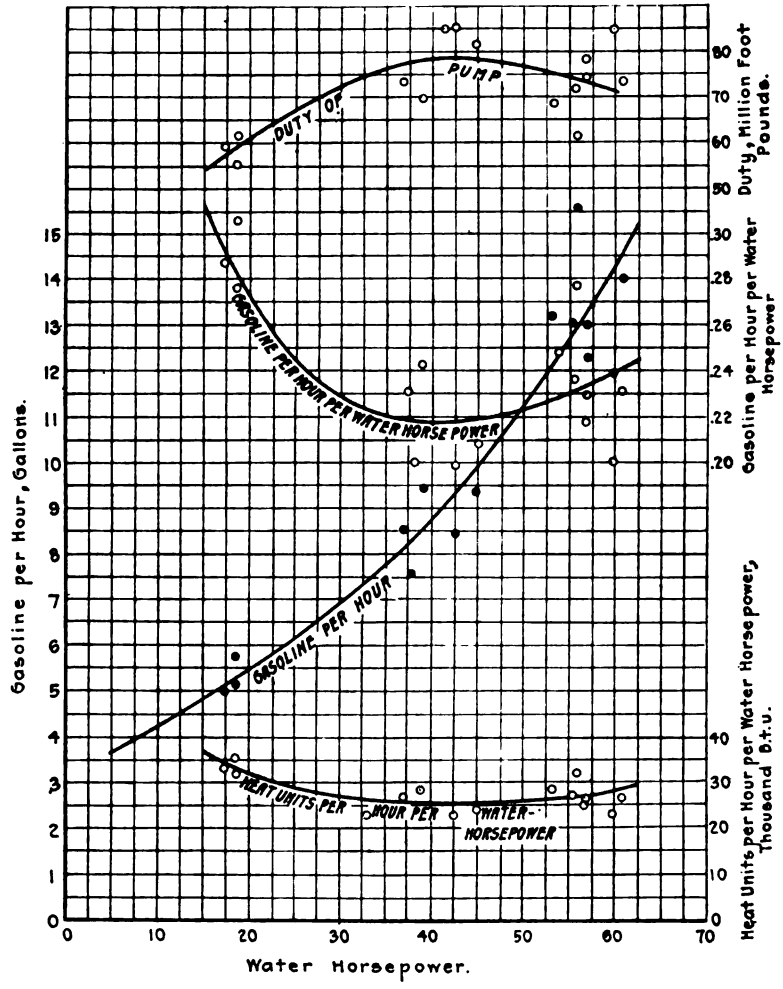

FIG. 10 PERFORMANCE CURVES FOR MOTOR FIRE ENGINE

29 The water horsepower may also be figured from the formula

$$\text{Water horsepower} = 0.000583\,GP$$

where

G = gal. per min.

P = total pressure in lb. per sq. in.

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30 Fig. 10 represents the *important results for the motor fire engine*, as a unit. Here are shown the total gallons of gasoline used per hour for water horsepowers at the pump ranging from 20 to 60; the gallons of gasoline used per hour per unit horsepower; the number of heat units supplied, and the duty of the pump.

31 The number of heat units is taken as equal to 117,000 B.t.u. per gallon (59.8 deg. Baumé, 0.738 specific gravity, 19,000 B.t.u. per lb.).

32 *Duty* is defined as the number of foot-pounds of work done per 1,000,000 B.t.u. supplied.

$$\text{Duty} = \frac{60 \times 33{,}000 \times 1{,}000{,}000}{\text{Gal. gasoline per hp. per hr.} \times 117{,}000}$$

$$= \frac{16{,}920{,}000}{\text{Gal. gasoline per hp. per hr.}}$$

TABLE 2 MAXIMUM CAPACITIES FOR VARIOUS SMOOTH NOZZLES UNDER CONDITIONS OF TEST FOR MOTOR FIRE ENGINES

Diameter nozzles, in.	Discharge press. at pump, lb.	Maximum capacity by weir, gal. per min.	Pitot gage readings, lb.	Capacity by pitot gage, gal. per min.	Deviation of pitot gage from weir, per cent	No. and length of hose line, ft.
1.121	249.6	360	105.0	384	6.4	One 500
1.246	242.0	383	71.0	393	2.4	One 500
1.370	236.2	399	57.3	425	6.0	One 500
1.500	157.3	637	94.9	656	3.0	Two 250, with Siamese union
1.750	133.5	693	61.3	718	3.4	Two 250, with Siamese union
2.000	121.9	745	43.3	788	5.5	Two 250, with Siamese union
Two of 1.246	134.0	720	64.5	747	3.7	Two 250
Average..	.....	.....	.....	.....	4.3	

The capacity as indicated by the pitot gage is seen by Table 2 to be on the average 4.3 per cent higher than that by the calibrated weir.

DISCUSSION OF RESULTS

33 *The maximum capacity obtained* during the test was 745 gal. per min., at 122-lb. pump discharge pressure with a 2-in. nozzle attached to a Siamese union with two hose lines each 250 ft. long, as shown in Table 2. This discharge is slightly below the rating of 750 gal. at 120-lb. net pump discharge pressure, and is accounted for by the fact that a 2-hose line instead of a 3-hose line was run from the engine. The loss of energy due to the drop of pressure in the line (76.4 lb.) represent 58½ per cent of water horsepower at

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the pump. With three lines in service the drop in the line would be 34.5 lb., so that a discharge of 250 gal. per min. per line (or a total of 750 gal. per min., requiring 44 lb. at the nozzle, a drop in the line of 35 lb. and a probable suction pressure of 8 lb.) would require the total pump-discharge pressure to be close to 44 + 35 + 8 = 87 lb., instead of 130 lb. If the pump had no suction resistance to overcome, that is, if the suction hose were shorter or if the water flowed to the engine under some pressure, about 6 per cent of the energy would be saved.

TABLE 3 WATER-HORSEPOWER OUTPUT AND GASOLINE CONSUMPTION FOR ONE, TWO, AND THREE FIRE STREAMS THROUGH 150-FT. TO 500-FT. 2.5-IN. HOSE LINES, USING 1⅛-IN., 1¼-IN., AND 1⅜-IN. SMOOTH NOZZLES

Nozzle diam., in.	Gal. per min.	No. and length of hose line, ft.	Pressure at nozzle, lb.	Drop in line, lb.	Suction gage, lb.	Total discharge at pump, lb.	Output, water hp.	Gasoline used per hr., gal.
1.121	250	One 150	53.0	20.7	3.77	77.47	11.3	4.35
		One 250	53.0	34.5	3.77	91.27	13.3	4.60
		One 350	53.0	48.3	3.77	105.07	15.3	4.85
		One 450	53.0	62.1	3.77	118.87	17.3	5.10
		One 500	53.0	69.0	3.77	125.77	18.3	5.25
	500	Two 250	53.0	34.5	5.70	93.20	27.2	6.50
	750	Three 250	53.0	34.5	7.90	95.40	41.8	9.15
	250	One 500	53.0	69.0	3.77	125.77	18.3	5.25
	500	Two 500	53.0	69.0	5.70	127.70	37.5	8.25
	750	Three 500	53.0	69.0	7.90	129.90	56.8	13.25
1.246	250	One 150	32.0	20.7	3.77	56.47	8.2	4.00
		One 250	32.0	34.5	3.77	70.27	10.2	4.23
		One 350	32.0	48.3	3.77	84.10	12.3	4.43
		One 450	32.0	62.1	3.77	97.87	14.3	4.76
		One 500	32.0	69.0	3.77	104.77	15.3	4.85
	500	Two 250	32.0	34.5	5.70	72.20	21.1	5.60
	750	Three 250	32.0	34.5	7.90	74.4	32.7	7.40
	250	One 500	32.0	69.0	3.77	104.77	15.3	4.85
	500	Two 500	32.0	69.0	5.70	106.70	31.1	7.10
	750	Three 500	32.0	69.0	7.90	108.90	47.6	10.6
1.370	250	One 250	24.0	34.5	3.77	62.27	9.1	4.30
	500	Two 250	24.0	34.5	5.70	64.20	18.7	5.30
	750	Three 250	24.0	34.5	7.90	66.40	29.0	6.80
	250	One 500	24.0	69.0	3.77	96.77	14.1	4.70
	500	Two 500	24.0	69.0	5.70	98.70	28.8	6.70
	750	Three 500	24.0	69.0	7.90	100.9	44.1	9.70

34 *Table 3 contains the horsepower output and gasoline* consumed for the three most commonly used nozzles and for one, two and

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three fire streams for 150- to 500-ft. lines. The values in the tables are taken from the curves plotted from the results obtained from these tests.

35 From this table may be noted the increase in lost energy due to increased friction in the line and also due to increase in resistance in the suction hose. For example, for the 1⅛-in. nozzle, 250 gal. per min., and varying hose lengths from 150 ft. to 500 ft., the increase in horsepower from 11.3 to 18.3 is necessary to overcome the increased frictional resistance in the hose line with increase of length.

36 For the same nozzle and one, two, and three lines of hose (500 ft. each), for 250, 500, 750 gal. per min., the variation in total heads, 125.8, 127.7, 129.9 lb., is due entirely to increase of suction-hose resistance.

37 *The gasoline used by the motor fire engine* may be read from the total gasoline curve, Fig. 10. The range of water-horsepower output was from 18 to 60 hp., with most of the tests grouped about 18, 40, and 55 horsepowers.

38 The average results as read from the curve are as given in Table 4.

TABLE 4 AVERAGE RESULTS FROM FIG. 10

Water-hp. output	Gasoline per hr., gal.	Gasoline per hr. per water hp., gal.	Heat units supplied per hr. per water hp., B.t.u.
20	5.45	0.272	32,000
40	8.75	0.218	25,500
60	14.35	0.240	28,000

39 The curves (Fig. 10) show that the most economical working point for the engine is about 40 water-horsepower output, at which point the least gasoline per horsepower is used and hence a horsepower is obtained with the least expenditure of heat units.

40 Assuming 50 per cent for the overall efficiency at the nozzle, which would seem to be a reasonable figure for efficiency of the pump and hose line, it is seen that the most economical conditions are obtained when the probable engine output is 80 hp., which is its rated power.

41 For 40-hp. output, 0.218 gal. of gasoline per hr. per hp. is used, which is equal to 1.74 pints of gasoline per hp-hr. An average value of 1 pint per hour per brake horsepower was obtained in 1912

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on a 4-cylinder Seagrave motor similar in type. The value of 1.74 pints for the complete fire-engine unit seems a consistent figure when the frictional resistance of the pump and hose line are taken into account.

COMPARISON WITH STEAM FIRE ENGINE

42 For the purpose of comparison the fuel consumption and fuel cost of a steam fire-engine unit are also given in Table 5. This steam fire engine, tested in 1911 at the University, was a "third-size" steamer, capacity of 600 gal. per min., rebuilt for the City of Columbus in 1906 and in continuous fire service up to date of test. It is regretted that tests for fuel economy on other steamers are not available at this time, and it is not the intention to place the steam-driven unit at any disadvantage in making these comparisons from the results of tests on only one steamer dating back ten years.

TABLE 5 FUEL COST OF MOTOR FIRE ENGINE AS COMPARED WITH STEAM FIRE ENGINE

Fire engine	Fuel per hour per water hp. output	Cost per hour per water hp. output
Steam	13.00 lb. coal	1.3 cents, with coal at $2 per 2000 lb.
Motor	0.218 gal. gasoline	5.5 cents, with gasoline at 25¢ per gal.

43 With prices as quoted above, the cost of producing the fire stream with the motor fire engine is about four times the corresponding cost with the steam fire engine, while the present prevailing prices would bring the costs more nearly equal. For the steam-engine unit the average steam used per hour per water horsepower is 55.9 lb. Allowing an average value of 85 per cent for mechanical efficiency the probable steam used per horsepower developed in the steam cylinders would be 47.5 lb. This value is a little higher than that usually quoted for steam engines of a similar kind and size but is much lower than is usually found in practice for the simplex direct-acting reciprocating steam pump. The advantage of the gasoline-driven engine is most noticeable when the comparison is made with the horse-drawn steamer, for the motor fire engine is able to reach the fire in half the time, is readily converted from the locomobile to the pumping engine, and is more easily and economically operated with the expense of maintaining the proper number of horses entirely eliminated.

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44 In one instance,[1] it was reported that the maintenance cost for a motor-operated engine, as computed for a period of 12 months, was one-fifth that of the horse-drawn steamer.

45 In another case,[2] the total maintenance cost of the motor fire engine was found to be one-half that of the steam fire engine, also covering a period of 12 months.

46 When the duty of the engines is considered the advantage is to be seen on the side of the motor fire engine, which has a duty of 77,600,000 ft-lb. per million B.t.u., as against 13,500,000 ft-lb. for the steamer pump. With the most modern types of steam fire engines it is not likely that the duty would exceed one-half that obtained with the motor fire engine.

47 W. S. Winnard, Superintendent of Machinery of the Columbus Fire Department, has also observed while operating the two classes of fire engines that the centrifugal pumping unit gives by far the steadier stream and, owing no doubt to the freedom from pulsations, the line drop is also much less than when using the reciprocating pump with the same hose line.

48 In conclusion, it may be said that the motor fire engine is fully the equal of the steam fire engine in fire-stream capacity, and, except as to a slightly higher fuel cost at prevailing prices, is without doubt its superior in steadiness of pump action, as a time saver, in flexibility, in ease of operation, and in reduced cost of maintenance, especially when compared with the horse-drawn steamer.

DISCUSSION

CLAUDE M. GARLAND (written). The motor fire engine, like many other pieces of apparatus, does not depend for its success upon thermal efficiency or fuel economy. The results in the paper indicate, however, a combined thermal efficiency from engine to water horsepower of approximately 10 per cent, which would doubtless indicate a thermal efficiency of engine of something like 20 per cent. This is a very satisfactory performance.

The differences in fuel costs, as shown in the paper, between the steam- and the motor-driven engine are, however, hardly representative of actual conditions. It is seldom necessary to pay 25 cents a gallon for gasoline; eighteen cents is probably an average figure. It is hardly probable that coal suitable for use under the boiler of a

[1] *Fire and Water Engineering*, vol. 48, 1910, p. 234.
[2] *Fire and Water Engineering*, vol. 53, 1913, p. 94.

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fire engine can be obtained for $2 a ton; $4 would probably be more nearly an average figure.

As the fire engine is seldom in operation for more than a few hours a day, the item of fuel cost is undoubtedly negligible when considered with the advantages of high speed in travel, the saving of time in starting, and the elimination of feed and upkeep on horses.

E. W. ROBERTS [1] pointed out as a matter of interest that no horse-drawn fire apparatus had been built for several years, and that as rapidly as possible all the cities in the country were installing motor-power apparatus.

WM. T. MAGRUDER said that in his opinion the paper might be considered as a foundation paper, from which to judge future performances of motor-driven fire engines.

THE AUTHOR, in closing, said that it might be well to point out that the unit described in the paper was operated entirely by the fire-department operators. Those who conducted the tests had nothing to do with the adjustment of the motor or anything else pertaining to the engine. All they did was to look after the accurate measurements of the fuel and the water pumped. The results presented could therefore be regarded as average results closely approaching actual operating conditions for the type of engine tested.

Referring to the discussion on fuel costs by Mr. Garland, it should be stated that the cost prices of the fuel, as quoted in the paper (Par. 42), were those reported as prevailing in Columbus in April 1916. The fuel-cost comparison, therefore, should be taken as representative of local rather than of average national conditions.

[1] Consulting Engineer and Editor, *The Gas Engine Magazine*, Cincinnati, Ohio.

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No. 1595

THE DESIGN OF MOTOR-TRUCK ENGINES FOR LONG LIFE

By John Younger, Buffalo, N. Y.
Member of the Society

The problem of long life of a motor-truck engine is not a simple one, on account of the widely varying conditions under which the engine operates.

Long life depends on three factors: Design, manufacturing excellence, and operating conditions.

Design: Under this head the paper summarizes present practice, giving particulars of recommended materials, dimensions of parts, and factors of safety for the several parts of the engine.

Manufacturing Excellence: Workmanship, tolerances, and running tests are considered. For long life the best workmanship is essential.

Operating Conditions: Recommendations for maintaining the engine in first-class condition are given. For long life particular attention should be paid to lubrication, cleaning, inspection, and regulation.

THE question of *life* in a motor-truck engine is naturally one which the engineer must compromise. An intense search after long life, to the exclusion of everything else, would result in a monstrosity which would be too heavy, too bulky and too costly to run.

2 An approximate definition of *long life* would, therefore, be "that length of life which is something more than the average expected life, based on present-day knowledge and all-around conditions."

3 At the present day a life of 50,000 miles, without overhaul, would be considered long. This would correspond to a continuous run day and night for 12 months, at a speed of about 400 r.p.m., with no attention beyond oiling and fueling. The load will fluctuate between less than zero (as when in coasting down hill with clutch in, the chassis drives the engine) to the full power of which the engine is capable. The majority of the hauling will be done at an average of ¼ full engine power. An engine should be capable of at least five or six overhauls, or 300,000 miles, before renewal of the major parts.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of The American Society of Mechanical Engineers.

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4 This does not look at all severe to the casual glance of the power-house engineer, but when one considers that this power plant is operating under widely varying temperatures, power and speed conditions, and that its various axes are constantly changing relatively to the bed to which it is fastened, it will be seen that the problem of long life is not so simple as it looks.

5 Long life depends on three factors: (1) *Design*, (2) *Manufacturing excellence*, (3) *Operating conditions*.

DESIGN

6 This may be considered under headings such as: *a*, bearing surfaces; *b*, lubrication facilities; *c*, materials used; *d*, factors of safety; *e*, general design and use of governor.

7 *Explosion Pressure.* All calculations should be based on full load, not on average load. This can be taken as an explosion pressure of 300 lb. per sq. in. on the piston with a 22 per cent compression volume.

8 *Connecting-Rod Bearings.* The pressure per projected square inch should be about 700 lb. per sq. in., excluding area of oil leads and fillets at ends, or 1 sq. in. per 2.33 sq. in. of piston area.

9 Oil is conveniently introduced through a hole in the crankshaft, and the bearing may either be grooved with a slightly spiraling oil groove around the whole circumference, or a groove around the bottom half only, or a series of slots or labyrinth checks on the sides, or even no grooves at all. Any of these methods prevent ridges wearing on the crankshaft.

10 The bearing itself should be a thin shell of hard babbitt metal about $\frac{1}{32}$ in. thick, backed up by a thick shell of hard bronze running on a case-hardened or otherwise hard surface. This gives the advantages of the babbitt as a bearing metal, and prevents it from pounding out. The bronze should be carefully tinned and have peg holes in it to give perfect union between the two. The running clearance should be small, between 0.0015 in. and 0.0025 in., satisfying practically all truck engines. The split surfaces should be carefully fitted together to prevent rocking or catercornered work.

11 *Gudgeon or Wrist-Pin Bushings.* Owing to the slight oscillatory motion, pressures may be higher. Under the conditions of space and the necessity for keeping down the weight of reciprocating parts, they may be as high as 1800 to 2000 lb. per sq. in. (or 1 sq. in. per 6 sq. in. of piston area).

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12 Lubricating oil should be brought by a small tube (where pressure lubrication is used) direct to the bearing and allowed to ooze out. The majority of bushings are at present lubricated on what might be called the "chance" method — the chances being, however, chiefly against. The metal should be a very hard chill-cast phosphor bronze, running on a case-hardened steel surface.

13 Running clearances should be kept exceedingly low, 0.00025 in. being satisfactory. Very little tolerance should be allowed.

14 *Pistons.* The side bearing pressure is low, inasmuch as the facilities for lubrication are poor. Sixteen pounds per projected square inch is satisfactory. The piston should be as light as possible consistent with strength, so as to minimize the loads due to the reciprocating masses.

15 Three rings above the gudgeon pin are ample. They should be thick radially, and preferably of the concentric type, to even the pressure on the slots and prevent them wearing away. The S.A.E. standard for piston-ring grooves is

$$G = \sqrt{\tfrac{1}{8}\,(0.01\,D^2) + 0.005}$$

where G is depth of groove, and D is nominal diameter of piston, both in inches. A pressure of about 10 to 12 lb. per projected sq. in. is ample to keep the rings against the cylinder walls.

16 The piston should be made of a softish gray cast iron, running against a harder cylinder metal. The clearance should be great at the top to allow for expansion due to heat, being four times the piston diameter in thousandths above the top ring, and equal to it in thousandths on the skirt. This bearing surface is, as a rule, relieved around the gudgeon pin.

17 *Cylinders.* Cylinders should be of a hard, close-grained, high-tensile-strength cast iron. Its scleroscope hardness (though this is of doubtful value) will be found to be about 35. It should be made thick enough in the walls so that actually about 0.060 in. may be ground off the diameter to take care of wear, without causing weakness. For a 5-in. bore cylinder, $\frac{5}{16}$-in. walls are sufficient.

18 *Crankshaft.* Three bearings — front, center and rear — are considered ample for a 4-cyl. truck engine. Consider the area of the connecting-rod bearing (big end) as 1, then the front and center bearings may have an area equal to 1 and the rear bearing 1.5. If the splash or trough system of lubrication is used, the areas of the front and center bearings should be increased to about 1.2.

19 An approximate rule for the diameter of crankshafts in the

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usual sizes of motor-truck engines, is that the square of the cylinder bore shall be twice the cube of the crankpin. This gives a 2-in. shaft for a 4-in.-bore engine, and about a $2\frac{7}{16}$-in. shaft for a 5-in.-bore engine.

20 Running clearances lie between 0.0015 and 0.003 in., depending somewhat on the nature of the lubrication.

21 The bushings should be similarly constructed to those on the connecting-rod big ends, except that the spiral oil groove will probably be found preferable to give a continuous supply of oil to the connecting-rod bearings.

22 The material should preferably be about 0.40 to 0.50 per cent carbon steel, carefully heat-treated to give a tough, hard surface (scleroscope 36 to 40). The larger-diameter shafts should have a percentage of chromium and nickel to ensure better heat treatment and resistance to fatigue.

23 Low-carbon, case-hardening material is sometimes used, but the shaft has to be increased in diameter to compensate for the lessened resistance to fatigue.

24 Good-sized fillets, no machine-tool scratches and general smoothness of outline will materially help long life.

25 *Camshafts.* Camshafts should be made of a low-carbon steel, case-hardened on the wearing surfaces. The bushings should be of a good grade of phosphor bronze. Three bearings are ample for a 4-cyl. car. The diameter of the shafts should be from 1 in. to $1\frac{1}{8}$ in., for the sake of smooth operation. The projected area of the bearings, front to rear, should be approximately 4 sq. in., 3 sq. in. and 2 sq. in., depending somewhat upon whether oil pumps or governors are driven from the camshaft.

26 *Valves.* The cams operating the valves should be so designed that just before the valve seats itself the velocity will be considerably diminished, allowing the last few thousandths of its travel to take place in a comparatively long time. This prevents the valve hammering on its seat. It does not interfere with the fuel economy or power, but gives quieter action.

27 A 45-deg. valve seat is advisable, as carbon will not be driven into the seat, but will more easily clear itself.

28 Valves containing a percentage of tungsten from 2 per cent upward are most satisfactory as regards life and freedom from warpage. By scleroscoping them while hot, they will be found to hold a hardness of over 40. Cast iron remains about 30, while other steel and nickel alloys drop to 25 or lower. The tungsten valve has thus a reason for its long life.

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29 *Sundry Parts.* The rest of the engine should be designed in proportion, such as wide faces on the timing gears and ample bearings for their spindles. The water pump should have ample bearing area, and if of the centrifugal type proper, provision should be made for the thrust of the blades.

30 Studs may be used for fastening down the cylinders, but they should have a length equal to twice their diameter screwed into the aluminum alloy, if such be used. A coarse thread is necessary, but for all purposes where aluminum is concerned, best results are obtained by the use of through bolts.

LUBRICATION

31 Considerable change has taken place in this in the last few years, although even yet all questions have not been settled, and cylinder lubrication is still somewhat on the hit-and-miss principle.

32 The method most in favor at present is to carry a supply of oil, about one gallon, in the crankcase of the engine, and pump it under a pressure of anything between 2 lb. and 20 lb. per sq. in. to a header pipe, from which issue leads to the crankshaft main bearings, and often the camshaft and timing-gear bearings. The surplus oil is bypassed by a regulating valve back to the crankcase. This oil and that which has done its work in the cylinders and crankshaft and various bearings drains down to the bottom of the case through a strainer and thence into the pump to renew the circuit.

33 When the oil gets dirty enough — or say every 300 miles or so, it ought to be thrown out and replaced with clean oil.

34 The system described works surprisingly well when it is considered that a certain amount of gasoline filters past the pistons and dilutes the oil — that some of the aqueous products of combustion also get past and help form an emulsion.

35 However, it can only be a matter of time before the adoption of some much better system of introducing fresh, clean oil to each bearing in predetermined quantities. Many oils are on the market and most of them are good.

36 Incidentally, as a point of design, it should be made easy for the driver to make sure that his oil is in good condition and of ample quantity.

MATERIALS AND FACTORS OF SAFETY

37 Naturally, extreme consideration has not been given to weight, as has been in the case of aeroplane engines, when 2½ lb. per

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hp. has been reached. A fair weight for a motor-truck engine is nearer 20 lb. per hp. at a piston speed of 1000 ft. per min. Aluminum is used for the crankcase and its covers. Cast iron is used for the cylinders and pistons; 0.40 to 0.50 carbon steel is used for the crankshaft and connecting rods. Case-hardening steel is used for the camshafts, valve tappets and gudgeon pins.

38 In order to ensure the proper factor of safety being maintained, it is advisable to scleroscope each part for correctness of heat treatment or hardness. Forgings like connecting rods, camshafts, crankshafts, should be straightened before machining.

39 The general design should be such that extreme climatic conditions can be guarded against. Roads, for example, in winter time are exceptionally bad, causing a weaving of the bed of the engine as would correspond to one of the wheels being lifted 12 in. off the road. The engine should be mounted so that no stress due to this will come on the moving parts.

40 The engine power should be ample for its work. Too much gear work is detrimental to long life. The transmission reduction should be such that the great majority of road work should be done on high gear. For instance, the hilly city of Cincinnati requires a lower transmission ratio than would the comparatively level cities of Buffalo or Cleveland. This prevents the engine from working at maximum capacity for too much of the time.

41 Speed should be carefully limited. A maximum piston speed of 1000 ft. per min. is desirable, and drivers and purchasers should be educated to the economy of a governor which will enforce this. The governor should be so designed that it will not restrict the power, but should go in or out of action with a maximum 5 per cent variation in speed round the predetermined point.

MANUFACTURING EXCELLENCE

42 Too much stress cannot be laid on this. Poor workmanship cannot be tolerated in an internal-combustion engine. Cylinders should be ground to a maximum tolerance of 0.002 in., as should pistons, and in addition a process of selection must be used which will ensure pistons on the high limit being put into cylinders of the low limit. The running clearances should not vary by more than 0.002 in.

43 Pistons, complete, should be weighed, the maximum variation in any one of a set being not more than $\frac{1}{2}$ oz. Similarly, connect-

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ing rods should be weighed and balanced, the variation in one of a set being not more than ½ oz., with the ends varying also by as little.

44 Connecting-rod and crankshaft bearings should be selected so that a maximum variation from standard running clearance of 0.001 in. plus or minus should be adhered to.

45 There is some diversity of opinion as to the best way to finish these bearings, but the writer believes that a reamed bearing is superior to the usual hand-scraped one. Reamers mounted on a rigid bar will true up crankshaft bearings in a way impossible by the hand reamer. Further, the surface left is as nearly round as possible, corresponding to that of the ground crankshaft. The personal element in hand scraping is entirely eliminated.

46 Crankshafts should be ground smooth with a maximum variation of 0.0015 in. in diameter and 0.001 in. eccentric. Each shaft should be scleroscoped at every bearing. Similarly with the camshafts, pump and magneto-drive bushings and so forth, a uniformly high standard should be insisted on.

47 It follows naturally that rotating parts should be put in static and dynamic balance.

48 When the engine has been assembled, it should be placed on a stand and run in. Here again opinions differ, but the writer believes a run of at least 30 hours, at a piston speed of about 800 ft. per min., varying the load from zero at the start to practically maximum for one or two hours at the finish, is necessary.

49 Most of this test, if indeed not all, should be done with some kind of fuel, either gas or gasoline, to get the engine thoroughly warmed up. This will ease off the high spots, let the valves find their seats, and generally take the harshness out of the engine.

50 At the end of this run the engine should be partially disassembled and valves reground, piston rings touched up, carbon cleaned, and the engine carefully inspected for signs of wear or scoring flaws.

51 When reassembled, the engine is ready for work.

OPERATING CONDITIONS

52 One of the secrets of success in gasoline engines is oil and lots of it. After a comparatively short run the oil (in the average system) is contaminated by gasoline and carbon. It should be drained out every 150 to 300 miles and replaced entirely by fresh oil.

53 The strainers leading to the pump should be kept clean and inspected frequently.

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54 About once a month the whole engine should be cleansed by washing it out with kerosene, turning the crankshaft by hand and thoroughly draining the kerosene all out.

55 Screens should be provided on the air intake to the carburetor to prevent entrance of road dust as much as possible.

56 Gasoline should be cut down in the carburetor as much as possible, not only for the sake of economy in consumption, but also for the prevention of harmful effects by an overplus.

57 The point of igniting should be properly controlled, so that evils following an "advanced spark" will not result.

58 Drivers should change to a lower gear immediately there are signs of the engine laboring.

59 Drivers should be carefully selected and trained men. Good horse drivers make good truck drivers, as they are accustomed to giving care and attention to their "motive power."

60 A regular system of inspection should be carried out by a good mechanic to detect any signs of trouble developing.

61 It is understood that hilly country or heavy roads will materially add to the work the engine has to do, and that the life will be proportionately shortened and inspection and overhauling will have to be done more frequently.

DISCUSSION

E. W. ROBERTS[1] said that one or two points in the paper were rather astonishing to him, and quite against his experience. A tolerance for the cylinder and the piston of 0.002 in. was generally considered by manufacturers far too large. He believed that such large tolerances were a mistake, because the workmen were apt to get careless. He had never heard of a tolerance for a cylinder or piston of over 0.001 in. While larger tolerances could be allowed, tolerances of 0.0005 in., nevertheless, made the men more careful.

He disagreed with the author's contention that spiral oil grooves would be found preferable for bearings. He said that one of the greatest mistakes made by manufacturers of engines of all kinds was in the shape of the oil grooves in the bearings. Experiments made at Cornell by Bierbaum nearly twenty years ago showed that the proper form of oil groove was the H-groove and not the spiral groove or the X-groove. In engines having lubrication troubles, or hot

[1] Consulting Engineer and Editor, *The Gas Engine Magazine*, Cincinnati, Ohio.

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bearings, if the change were made from the spiral to the H-groove the trouble would generally disappear.

Referring to the general idea that carbon was produced by the lubricating oil, Mr. Roberts said that it was not generally recognized that an over-rich mixture was quite a prolific source of carbon, because oxygen has a greater affinity for hydrogen than it has for carbon. The fuel being in excess, the oxygen combines with the hydrogen first, then with just so much carbon as the remaining oxygen will absorb. The result is that the excess carbon appears as a deposit. This fact has been proved by experiment. It shows that the general idea that all carbon is due to lubricating oil is not altogether true.

K. T. KELLER discussed the author's statement that "When the oil gets dirty, say, every three hundred miles or so, it ought to be thrown out and replaced with clean oil." In his experience in the testing of engines he had found that the oil could be used over and over again if properly handled. It was not necessary to filter it in the sense of restoring its original color, but by running it through a separator of the cream-separator type the heavier particles of matter that had accumulated in it could be taken out, and the finer carbon or graphite was very beneficial to the engine. He had found, however, that oil used over and over without running through a separator broke down and contained considerable muck or gummy substance, which collected in the bottom of the oil pan, and which was sometimes due to water getting down and breaking up the oil, or particles of dirt getting in.

Regarding tolerances for cylinder and piston, he differed with the author, and thought that pistons on the high limit should be put into cylinders on the high limit and pistons on the low limit into cylinders on the low limit, so as to maintain a uniform amount of clearance.

F. A. WHITTEN[1] (written). I believe that operating conditions have more effect upon the long life of truck engines than design and manufacturing excellence combined. The motor-truck manufacturer, unfortunately, has practically no control over the operating conditions. He has applied governors, screens, and other devices in an endeavor to protect his machine from abuse, but drivers do not like them.

[1] General Motors Truck Co., Pontiac, Mich.

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Generally speaking, owners have no workable system to determine whether the manufacturer's devices are being used or his instructions carried out. Any investigation along this line is usually of the sort which results in locking the barn door after the horse is stolen. A tremendous amount of education of the owner is required in order to attain proper results. The first trucks a man uses are frequently condemned as unfit for the service because of the way in which they are operated. We have very little difficulty with trucks in the hands of those who have had previous experience in operating, as such owners have usually already learned their lesson from the results of neglect and careless handling.

As the author states, "oil and lots of it" is one of the principal features of successful operation. Actual breakages are rare, and lubrication troubles are responsible for most operating troubles and delays.

The carburetor is not usually considered a part of the engine, but I believe it should be so considered, as the success or failure of the engine depends upon the carburetor in more ways than are generally recognized. Investigation will show that present-day lubrication troubles are usually intimately related to the carburetor and fuel. That the low-grade fuel generally used today is responsible for many troubles, is a fact not generally recognized by operators.

The driver should not be given control over the carburetor adjustment except to a very limited degree. Choking the air supply to produce a rich mixture for starting may be necessary, but forcing the engine to pull its load before it is warmed up may be a very expensive procedure if persisted in. This rich mixture, with present grades of fuel, is almost certain to carry into the cylinders a certain amount of fluid fuel which destroys the oil and results in piston-ring and cylinder wear. This liquid fuel also works down past the pistons and destroys the lubricating oil in the crankcase. Not only is the oil spoiled in this way, but the liquid fuel loosens small particles of carbon dust and carries this down into the cylinders and the crankcase, whence it will be distributed into the bearings in spite of any screen which may be provided. By the use of a rich mixture, either in starting the truck or by bad all-around carburetor adjustment, it is possible to wear out a motor in a very short time.

The danger of this sort of operation is self-evident to any engineer, but it seems very difficult to get the user to appreciate the necessity for care of this sort or to believe he is in any way responsible for troubles caused by such operation.

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H. E. MORTON (written). The lubrication of an internal-combustion engine of the multi-cylinder so-called high-speed class involves a variety of problems. The conditions are severe and in most cases the engines receive little attention, so that the real successful system has to be reliable, self-contained, efficient and fitted with indicating devices to give early warning of an exhausted oil supply or irregularity in operation.

The three systems most used are full-splash, full-forced, and a combination of the two. The individual pump and distributor system is seldom employed on modern engines. There seems to be no special merit in the full-splash system except low cost. The full-forced and combination systems are both good, but the former, properly designed and applied, will give excellent results and has the great advantage of making possible the highest unit bearing pressures all through the engine. The belief has existed in the minds of some that this higher loading is made possible by a sort of counterbalance equal to the oil pressure, but there is little to substantiate this theory. "Forced-volume system" might be a more significant name for the system, as tests indicate that it is the volume of oil forced through the bearings which is most important. The volume of oil rapidly carries away the heat generated, immediately replaces a break in the oil film due to momentary heavy loading, and thus allow the use of very high unit bearing pressures. All the above-mentioned systems make use of what may be loosely termed splash for cylinder-wall lubrication.

To make any one of these systems practical it is necessary to use the oil over and over, passing it through suitable filters each time, of course. Also for ordinary-duty engines all the oil is carried in the lower part of the crankcase. These conditions mean that a great deal of loose carbon is washed into the oil, and as it is so fine that the ordinary wire gauze will not remove it, the pump continues to pass it through the system. This particular point should not be lost sight of, for the carbon particles are quite effective as a lubricant and tend to hold up the viscosity of the oil. A good mineral oil under such conditions appears to lose very little in lubricating value after long use, especially if occasionally well filtered.

For exceedingly high-duty engines, such as those designed for aeroplane service, the practice of carrying all the oil in the crankcase is questionable. Oil temperature needs to be kept down, and with a secondary external circulating system and supply reservoir it can be fully controlled. Actual service tests covering many months show

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that good oil can be used almost indefinitely, employing an external circulating system and carrying very little oil in the crankcase.

THE AUTHOR. Mr. Roberts stated that a clearance of 0.002 in. is generally considered by manufacturers far too large. I do not understand where he gets this impression, as in dealing with motor-truck engines of 4- to 5-in. bore, a *maximum* variation in clearance of 0.002 in. can be allowed, and it is certainly inadvisable to come below a clearance of at least 0.003 in. on the skirt of the piston; preferably, in accordance with my experience, 0.001 in. per inch diameter of piston.

I think that in Par. 42 I should have been a little more careful in explaining exactly what was meant by a process of selection. It simply means, however, that while cylinders can be ground to a maximum tolerance of 0.002 in. and the pistons finished to a similar tolerance, a total tolerance of 0.004 in. should not be allowed in the engine, but that, as stated, pistons on the high limits should be put into cylinders on the low limits. This holds for the rest of the engine as regards connecting-rod bearings, etc.

If Mr. Roberts will refer to the paper, he will see that on connecting-rod bearings the bearings should be grooved with a slightly spiraling oil groove, to prevent ridges wearing on the crankshaft. This is not at all the figure-8 oil groove that probably Mr. Roberts is thinking of, but is simply a one-revolution spiral of a pitch very slightly in excess of the width of the groove. This has been found in combination with labyrinth checks to be exceedingly satisfactory. The H-groove is, as far as I know, obsolete in automobile-engine practice. Quite a number of firms are using successfully no grooves at all.

I am afraid I must disagree with Mr. Keller entirely. Oil at the rate of one gallon every two or three hundred miles is so cheap that it should be thrown away, and filtering or separating need not be resorted to.

It must be remembered that a great majority of motor trucks are running in places where mechanical separators cannot be easily obtained, and it is very questionable if the labor and cost involved in separating a gallon a week would be worth the trouble. Experience has distinctly shown, beyond all question, that the safest, most reliable way is to throw away oil every two or three hundred miles and replace entirely with clean oil.

Mr. Keller gives away his case entirely when he states that he

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noticed considerable muck or gummy substance accumulating in the bottom of the oil pan. This is due to water getting into the oil and products of combustion; also, in cold weather the rich mixture that is used in the carburetor to get the engine warmed up, will cause an excess of gasoline to drain past the pistons into the oil and accordingly waste the oil.

Mr. Whitten rightly emphasizes the point that operating conditions have a great deal of effect on the long life of truck engines. Designers and manufacturers have still to go a long way in order to make their machines fool-proof against even the most stupid operators. However, in all fairness to truck drivers, it must be stated that the last two or three years have seen very considerable improvement, and the average truck driver today is a reasonably intelligent operator.

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No. 1596

THE RELATION OF PORT AREA TO THE POWER OF GAS ENGINES AND ITS INFLUENCE ON REGULATION

J. R. DuPriest, Moscow, Idaho
Member of the Society

Any system of connecting up the governor of a gas engine to the throttle valve which gives equal changes in port area for equal changes in the governor speed, will make the regulation of the engine very sensitive at light loads and too slow at heavy loads.

The object of this paper is to present a method of determining the port area required for any fractional load on a throttling gas engine operating on the four-stroke cycle, and to suggest a means of admitting the fuel so as to get the same degree of speed regulation throughout the full range of load.

The author has made an extended study of the working of a 16½ × 24-in. horizontal double-acting tandem throttling engine, running on natural gas at 180 r.p.m., and from a consideration of the data obtained in tests and the characteristic curve of the governor used, has devised a method by means of which the relation between the travel of the governor collar and port area for a given power can be determined. A governing mechanism may then be designed which will give equal changes of load for equal movements of the collar, or the ports may be so shaped that equal changes in governor-collar travel will give equal movements of the valve, but at the same time give the proper port area for equal changes in power delivered.

THE function of a constant-speed governor on an engine is to control the speed within certain limits (depending on the class of service for which the machine is designed) while the load varies anywhere within the capacity of the engine. The ideal method of governing would be some system by which the change in load could be anticipated at the proper instant and the energy supply to the engine changed to suit the change in load, thus keeping the speed of the engine constant throughout the full range of load. This condition cannot be realised since it is impossible mechanically to anticipate such changes. Nevertheless, the speed of the engine must be held

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within the limits required by the conditions of operation by some suitable governing device.

2 In all types of governors dependence is placed on the change in speed of the governor to effect regulation, and when this governor is driven from the main engine the speed of the engine must change before the governor can act on the valve gear and exert any influence over the energy supply.

3 If the load on the engine increases, the order of changes in the governing system is as follows:

a Speed of the engine decreases

b Speed of the governor is reduced

c The change in the position of the governor, due to the change in speed, shifts the valve gear and supplies more energy to the engine to enable it to carry the increased load, and at the proper speed

d The speed of the engine increases, due to the increased supply of energy, hence the speed of the governor increases and the cycle above described is repeated in the reverse order. This action tends to produce a "hunting" effect on the valve gear and governor until the energy supply is properly proportioned to the existing load.

4 The amount the valve gear is moved for any slight change in speed of the engine and governor depends on the sensitiveness of the governor, the energy capacity of the governor and the mechanism connecting the governor to the valve gear.

5 If the valve, in responding to an increased load, opens too far and supplies more energy than is necessary, the speed of the engine will rise above normal, and the governing system will then reverse its operations and keep seeking a position of equilibrium, producing the objectionable hunting effect characteristic of too sensitive governors.

6 Apparently, the most desirable results would be obtained if the governor were so connected to the valve gear that equal movements of the governor collar would correspond to equal changes in load.

7 It might appear that any degree of regulation desirable could be secured by using a very sensitive governor, but it has been found by experience that in some cases — and particularly in gas-engine work — highly sensitive governors do not give as good results as those which allow a greater range in speed and do not respond so quickly to slight but quick changes, because the sluggish governor being more

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"stable" tends to eliminate the hunting action. Fortunately, for all ordinary work the allowable speed variation is great enough to permit the use of a stable governor.

8 In the regulation of the steam engine, where the steam is supplied under *high* pressure to the valve, the head producing flow through the ports and also the energy in a cubic foot of the steam entering the cylinder are practically constant since the boiler pressure and the quality of the steam remain essentially the same, but in the gas engine the conditions are quite different.

9 The energy supplied to the gas engine is in the form of a combustible mixture of air and gas the quality of which may vary considerably, also the head causing flow through the ports varies with every change in load if it is a throttling engine.

10 In the four-stroke-cycle gas engine the fuel mixture is made to flow into the cylinder by lowering the pressure in the cylinder below that of the atmosphere during the suction stroke, thus creating a difference of pressure sufficient to force in the charge.

11 The absolute pressure in the cylinder depends on the quantity of mixture entering the cylinder during the suction stroke. The amount of charge necessary in the cylinder depends on the load the engine is carrying, and therefore it is evident that a different amount is required for every change in load. Hence the absolute pressure in the cylinder during the suction stroke will be different for every different load, and the resulting pressure head causing the mixture to flow into the cylinder will be different.

12 This point can be most easily understood by neglecting temperature changes occurring during the suction stroke and assuming that the volumetric efficiency is merely a function of the difference between suction and atmospheric pressures. Since a light load calls for a small charge, it must correspond to a low volumetric efficiency. The low volumetric efficiency is always accompanied by a low suction pressure, due to the throttling at the valve, and therefore we have the peculiar condition that the greatest difference in pressure is available to cause flow when the least amount of mixture is required.

13 The result of this change in absolute pressure in the cylinder is such that when an engine is operating at say three-quarter load, with an apparent volumetric efficiency of about 67 per cent, and a change in load occurs which demands a volumetric efficiency of 77 per cent, it will require a much larger port area to give this increase of 10 per cent in volumetric efficiency at the heavy load than it would

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if the increase were from 30 to 40 per cent; the reason being that in the first case the head causing flow through the ports will be about 3.5 lb. per sq. in., while in the second case it will be about 7.5 lb. per sq. in.

14 On account of the greater head causing the charge to flow into the cylinder at light loads, it requires a very small change in port area for a considerable change in load. Therefore any system of connecting up the governor to the throttle valve which gives equal changes in port area for equal changes in the governor speed, will make the regulation of the engine very sensitive at light loads and too slow at heavy loads.

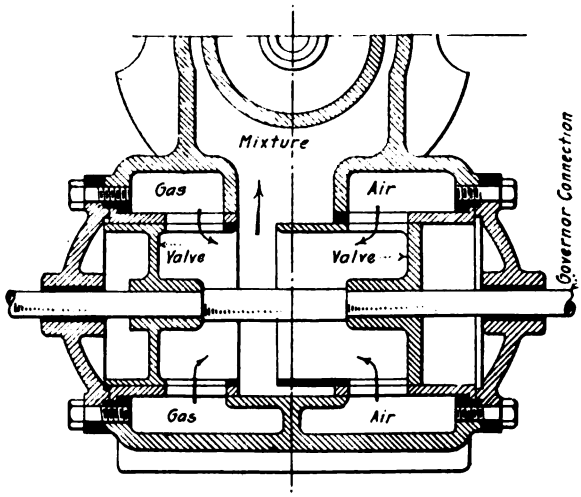

FIG. 1 SECTION THROUGH THROTTLE VALVE OF A HORIZONTAL DOUBLE-ACTING GAS ENGINE

DATA AND RESULTS FROM TEST

15 The test described below was made to find out as near as possible (1) the conditions under which the fuel mixture enters a gas-engine cylinder, and (2) the relation of port area to horsepower and its influence on the regulation of the engine. The results from the test are worked up and an effort is then made to apply theory to the changes taking place, and thus find a means of predicting similar results, for engines of the same type, before the machines are built.

16 *Method of Making the Test.* The engine tested was a 16½ by 24-in. horizontal double-acting tandem engine operating on natural gas.

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The test was made in the following manner: The throttle valve on the head end of No. 1 cylinder was disconnected from the governor and operated by hand, while the other three valves, under the control of the governor, took care of the load on the engine. The throttle valve shown in Fig. 1 is cylindrical, with six rectangular ports cut around the periphery which mate with similar ports cut in a surrounding sleeve when the valve rotates. The throttle valve is made to open and close in unison with the poppet inlet valve and is moved longitudinally by the governor to effect regulation. The travel of the valve was 2.5 in., and fifteen different settings were made varying from closed to wide open. Two sets of indicator cards were taken for each setting, one for indicated horsepower and the other for suction, two or more cards for each set being taken for every position of the valve. The results from these cards are given in Tables 1 and 2, from which data the curves of Figs. 2 to 7 were plotted.

17 In view of the fact that the indicator friction and inertia has considerable more effect on the suction cards than on the work cards, the data obtained seem very consistent. The curves were plotted and cross-checked to eliminate errors as far as possible.

18 *Determining Delivered Horsepower.* The load on the engine varied considerably during the test and, as there was no means of measuring the load, the delivered horsepower was found in the following manner:

19 After the test was over and the load removed several indicator cards were taken with the engine running at the proper speed and all valves properly connected but with only one cylinder end firing. These cards gave an average of 64 i.hp. for total engine losses, which consisted of machine-friction losses and the lower-loop losses.

20 From Fig. 3, the absolute pressure in the cylinder during the suction stroke, for 64 i.hp. is 9.65 lb. per sq. in., and with atmospheric pressure equal to 14.2 lb. per sq. in. this means that as the piston is moved out on the suction stroke there is a resistance of $14.2 - 9.65 = 4.55$ lb. per sq. in. due to the pump action.

21 In overcoming this resistance during the suction stroke the piston does work at the rate of $4.55 \times 1.07 = 4.87$ hp., which is a direct loss. (The factor 1.07 is the horsepower constant for one cylinder end of the engine.) A loss of 4.87 hp. per cylinder end gives $4.87 \times 4 = 19.48$ hp. loss for the engine, hence the machine friction $= 64 - 19.48 = 44.52$ hp., or 11.13 hp. per cylinder end.

22 If the machine friction for this load is assumed constant for

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all loads, which is very nearly true, the delivered horsepower for any load can be determined from the indicated horsepower by subtracting the loss due to the suction stroke, as measured by the suction card, and the loss due to the machine friction.

23 The maximum i.hp. for one cylinder end is 105 and from Fig. 3 the lower-loop loss for this load is 14.2 − 12.65 = 1.55 lb. per

TABLE 1 DATA FROM WORK CARDS

Port opening, in.	Length of card, in.	Area of card, sq. in.	Mean effective pressure, lb. per sq. in.	Indicated horsepower
¼	3.94	0.55	27.9	29.3
¼	3.94	0.55	27.9	29.3
½	3.92	0.96	49.0	52.5
½	3.90	0.98	50.8	53.7
¾	3.92	1.19	60.7	65.0
¾	3.94	1.15	58.4	62.5
¾	3.92	1.36	69.4	74.3
¾	3.92	1.37	69.8	74.8
⅞	3.90	1.58	81.0	86.7
⅞	3.92	1.57	80.2	86.0
1	3.92	1.75	89.3	95.6
1	3.92	1.73	88.3	94.5
1¼	3.90	1.75	89.8	96.1
1¼	3.88	1.80	92.8	98.5
1⅛	3.90	1.85	94.8	101.5
1⅛	3.92	1.86	94.8	101.5
1⅛	3.90	1.86	95.4	102.0
1⅛	3.91	1.86	95.2	102.0
2	3.91	1.90	97.2	104.0
2	3.92	1.86	94.8	101.5
2¼	3.92	1.90	97.0	103.8
2¼	3.91	2.00	102.4	109.5
2⅛	3.90	1.94	98.4	105.1
2⅛	3.94	2.04	103.6	110.6
2⅛	3.94	1.91	97.0	103.8

sq. in., which gives a loss of 1.55 × 1.07 = 1.66 hp. The engine friction per cylinder end as found above is 11.13, from which the maximum delivered horsepower (d.hp.) is found to be 105 − (1.66 + 11.13) = 92.21. If the maximum d.hp. of the engine is 92.21 per cylinder end and 10 per cent overload capacity be allowed, the rated load per cylinder end will be 92/1.10 = 83.6 d.hp.

24 *Delivered Horsepower for Different Load.* Assume the mechanical efficiency to be 86 per cent for full load and check as follows: 83.6/0.86 = 97.3 i.hp. From Fig. 3 the loss due to the suction stroke

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for 97.3 i.hp. is 2.1 lb. per sq. in., which gives $2.1 \times 1.07 = 2.25$ hp., therefore the total loss will be $2.25 + 11.13 = 13.38$ hp.; and $83.6 + 13.38 = 96.98$ i.hp., which checks very closely with 97.3 as assumed above.

TABLE 2 DATA FOR SUCTION CARDS

Port opening, in.	Length of card, in.	Area of card, sq. in.	Cylinder pressure, lb. per sq. in. abs.	Apparent volumetric efficiency
0	3.93	2.33	4.70	14.8
0	3.94	2.15	5.45	13.7
1/16	3.94	2.35	4.65	28.8
1/16	3.94	1.82	6.80	28.0
1/16	3.94	2.05	5.87	25.9
1/8	3.93	1.4	8.50	33.2
1/8	3.93	1.64	7.50	36.8
1/16	3.94	1.45	8.30	44.5
1/16	3.94	1.52	8.02	42.0
1/8	3.92	1.03	10.00	44.0
1/8	3.93	1.4	8.50	42.8
1/8	3.93	0.99	10.00	54.8
1/8	3.94	1.17	9.45	55.8
1/8	3.96	1.05	9.97	63.7
1/8	3.94	0.97	10.26	63.5
1/8	3.94	0.69	11.40	73.5
1/8	3.92	0.69	11.48	74.5
1	3.93	0.51	12.12	80.0
1	3.93	0.392	12.60	78.0
1 1/16	3.92	0.392	12.60	82.0
1 1/16	3.88	0.388	12.60	84.0
1 1/16	3.94	0.426	12.44	84.6
1 1/16	3.90	0.545	11.96	86.7
1 1/16	3.91	0.51	12.12	86.8
1 1/16	3.90	0.49	12.20	86.25
2	3.91	0.394	13.06	88.0
2	3.91	0.314	12.92	88.0
2 1/16	3.93	0.393	12.60	86.5
2 1/16	3.90	0.382	12.84	89.5
2 1/16	3.93	0.47	12.28	84.5
2 1/16	3.93	0.295	13.00	90.0

[1] Card not good.

25 The d.hp. for several values of i.hp. was found in the above manner and from the results the mechanical efficiency was calculated. The values for i.hp., d.hp., and mechanical efficiency are given in Table 3, from which the curves in Fig. 8 were plotted.

26 The mechanical efficiencies calculated above agree closely with the average values for machines of this type, and while the assumption made that machine friction is constant for all loads is not

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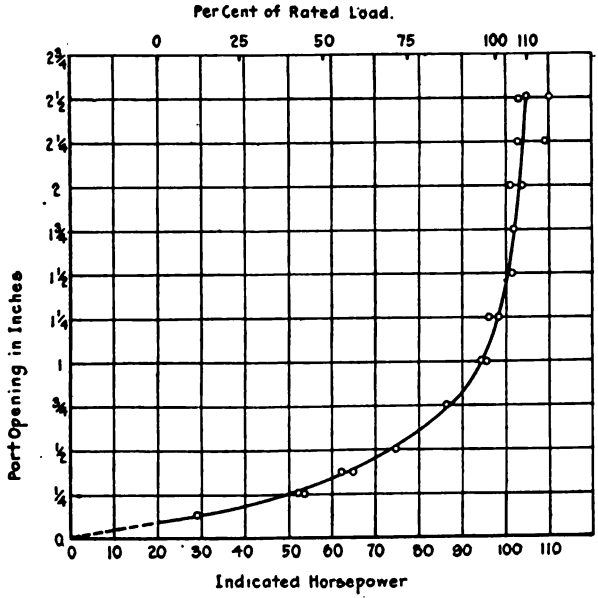

FIG. 2 RELATION BETWEEN INDICATED HORSEPOWER AND PORT OPENING

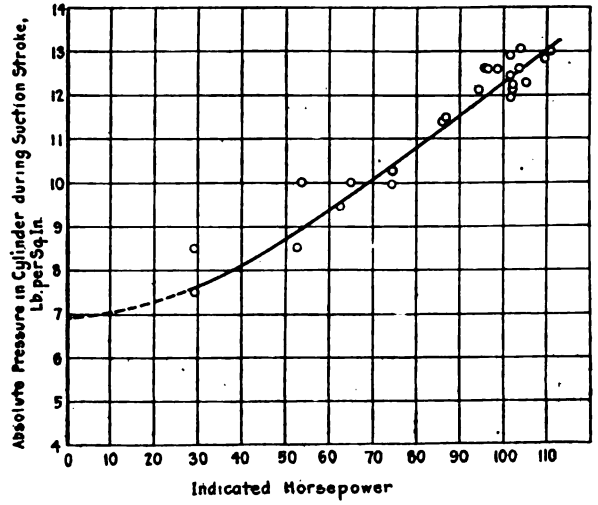

FIG. 3 RELATION BETWEEN INDICATED HORSEPOWER AND PRESSURE IN CYLINDER DURING SUCTION STROKE

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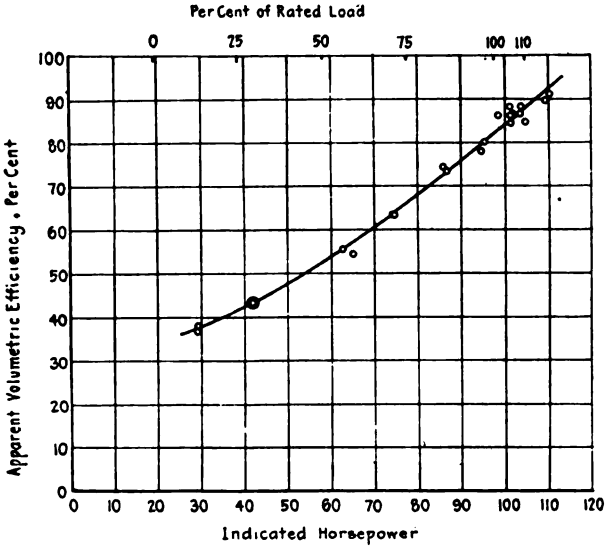

FIG. 4 RELATION BETWEEN INDICATED HORSEPOWER AND APPARENT VOLUMETRIC EFFICIENCY

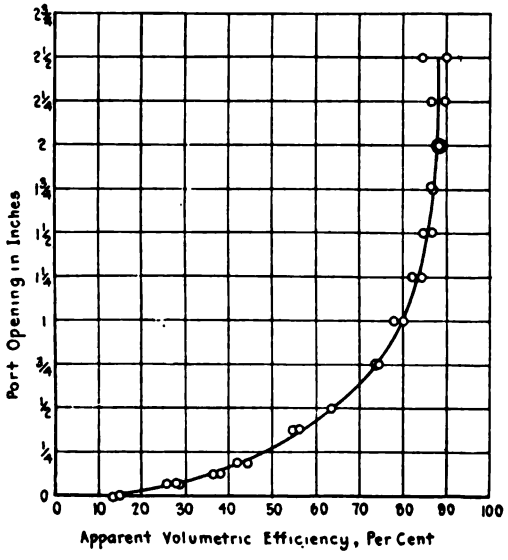

FIG. 5 RELATION BETWEEN APPARENT VOLUMETRIC EFFICIENCY AND PORT OPENING

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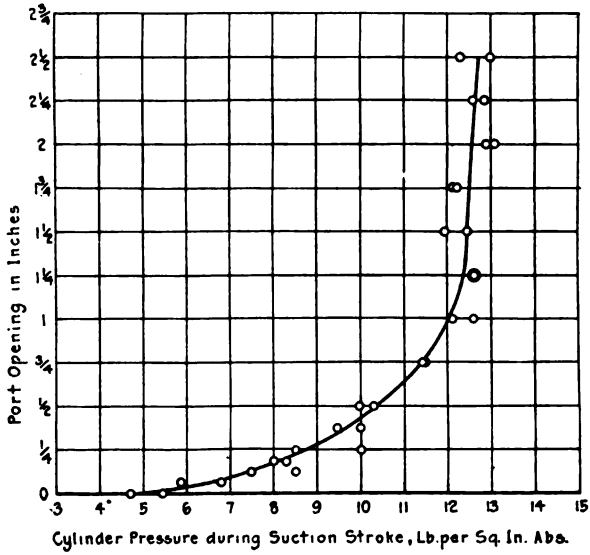

FIG. 6 RELATION BETWEEN PRESSURE IN CYLINDER DURING SUCTION STROKE AND PORT OPENING

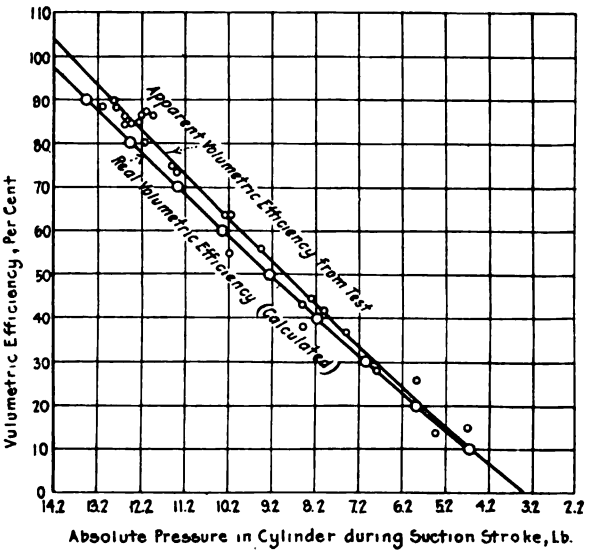

FIG. 7 RELATION BETWEEN PRESSURE IN CYLINDER DURING SUCTION STROKE AND VOLUMETRIC EFFICIENCIES

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true, it is believed that the error in this case is so small that it can be safely neglected.

27 Fig. 9 shows the relation between port area and d.hp. The data for this curve were obtained as follows: Delivered horsepower corresponding to any given i.hp. was taken from Fig. 8. The port openings as plotted in Figs. 2, 5 and 6 are linear dimensions, the ports being rectangular in shape, 2½ in. long by 1½ in. wide.

28 The mixing valve was rigidly connected to the inlet valve and opened and closed in unison with it. The cam arrangement was designed to give a valve-opening curve approximating the sine curve, with the maximum port width (H) 1½ in.

29 The effective port area under these conditions is $L \times H \times 0.637$, or the area of a sine curve having a base L and maximum

TABLE 3 CALCULATED VALUES OF DELIVERED HORSEPOWER AND MECHANICAL EFFICIENCY

Per cent rated load	Indicated horsepower	Delivered horsepower	Mechanical efficiency, per cent
0	20.00	00.0	00.0
25	39.28	20.9	53.5
50	58.00	41.8	72.0
75	77.30	62.6	81.0
100	97.30	83.6	86.0
110	105.00	92.0	87.5

altitude H. The port opening or length L of port for full load is 1.15 in., as shown in Fig. 2. Therefore the port area is $1.15 \times 1.5 \times 0.637 = 1.1$ sq. in. for each port and for six ports it is 6.6 sq. in. Port areas for one-quarter, one-half, three-quarter and full load were found in this way and plotted against delivered horsepower, giving Fig. 9.

30 From Fig. 9 it can be seen that when the engine is operating near the rated-load point it takes a large change in port area to effect a small change in the work developed by the machine, while at light loads a very small change in port area makes considerable change in the work done by the engine. The reason for this condition can be found by studying Fig. 3, from which it is seen that when the engine is operating at, say, full load the absolute pressure in the cylinder during the suction stroke is high, being 12.1 lb. per sq. in. absolute or 2.1 lb. per sq. in. below the pressure of the atmosphere, while at one-quarter load the absolute pressure in the cylinder is 8 lb. per sq. in.

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or 6.2 lb. per sq. in. below the pressure of the atmosphere. The amount the cylinder pressure is below atmospheric pressure is the head available to force the charge into the cylinder, hence the peculiar conditions noted above exist, that when the engine is operating at full load and requiring a large amount of charge the pressure head to produce flow into the cylinder is small, and when the engine is operating at light load and requires a small amount of charge a much larger pressure head is available to produce flow through the ports.

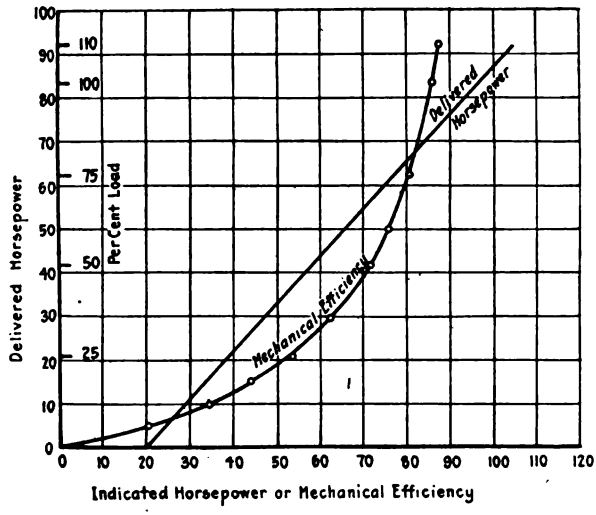

FIG. 8 RELATION BETWEEN DELIVERED HORSEPOWER AND MECHANICAL EFFICIENCY

31 From the above discussion and Fig. 9 it is evident that port area does not increase directly as the delivered horsepower increases, therefore, to get the same degree of regulation throughout the full range of load, some compensating device should be introduced between the governor and the throttle valve to take care of this condition. From Fig. 9 and the characteristic curve of the governor to be used, a mechanism can be designed which will give equal changes in load for equal movements of governor collar. This would seem to be a more desirable condition for good operation.

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THEORETICAL DEVELOPMENT

OUTLINE OF METHOD

32 It has been found from tests that the total heat consumption of an engine follows a straight line very closely when plotted against delivered horsepower, and by assuming a reasonable value for the B.t.u. per d.hp.-hr. for two points, say full load and quarter load, the total-heat curve can be drawn. From this curve with the heating value of the gas and the ratio of air to gas known the cubic feet of

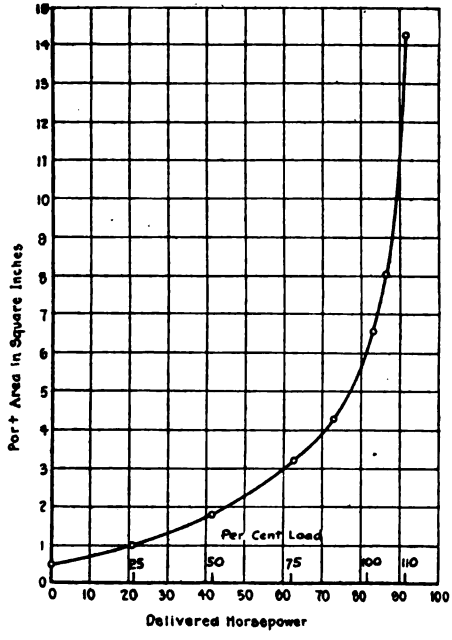

FIG. 9 RELATION BETWEEN DELIVERED HORSEPOWER AND PORT AREA

mixture required for any fractional load can be determined. This amount of mixture which must enter the cylinder occupies a certain volume under atmospheric conditions. At the end of the suction stroke it occupies the greater part of the piston displacement but is under some lower pressure p_2 which can be determined by the relation $p_1 v_1^N = p_2 v_2^N$, providing the proper value of N be known.

33 From analyzing a great many low-spring indicator cards taken from throttling engines it has been found that the absolute

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pressure in the cylinder during the suction stroke remains nearly constant throughout the greater part of the stroke, except for light loads. For the purpose of this discussion it can be assumed to remain constant without serious error and will be the pressure p_2 of the charge when occupying the new volume as found from the equation above. The difference between the absolute pressure in the cylinder during the suction stroke and the pressure outside the cylinder is the head causing the charge to flow through the ports.

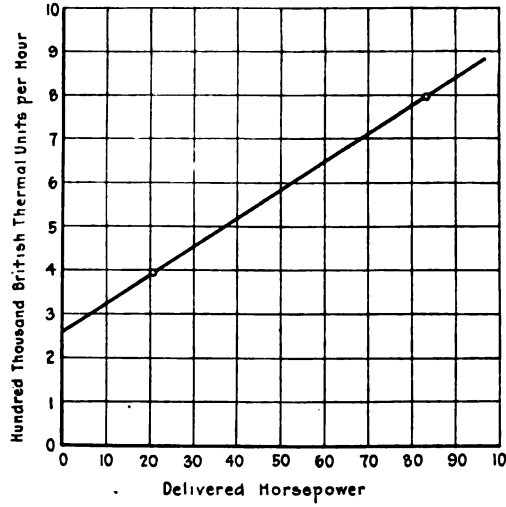

FIG. 10 RELATION BETWEEN DELIVERED HORSEPOWER AND TOTAL HEAT CONSUMED

34 Knowing the amount of mixture required and the head producing flow, the area of the port necessary to pass the given amount of charge can be determined. In the above manner the amount of mixture required for any given load and the port area necessary to pass this charge can be determined, thus giving a relation between power and port area.

APPLICATION OF METHOD

35 *Amount of Mixture Required.* The problem will be worked out for the machine described in the above test which is a 16½ by 24-in. horizontal double-acting tandem engine operating at 180 r.p.m. on natural gas of about 950 B.t.u. per cu. ft. As the four cylinder

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ends are all alike, it will be necessary to make calculations for one end only.

36 It will be safe to assume that the engine will require 9500 B.t.u. per d.hp.-hr. for full load and 19,000 B.t.u. per d.hp.-hr. for one-quarter load. These values are conservative and the engine tested showed much lower heat consumption than this. Fig. 10 shows the total-heat curve based on the above values, which correspond to thermal efficiencies referred to d.hp. of about 27 per cent at full load and 13.4 per cent at one-quarter load.

37 The theoretical amount of air required for combustion of one cubic foot of natural gas is about 9 cu. ft. and allowing 40 per cent excess air — which has been found to give good results, gives 12.5 cu. ft. of air per cu ft. of gas, or an air-to-gas ratio of 12.5 to 1.

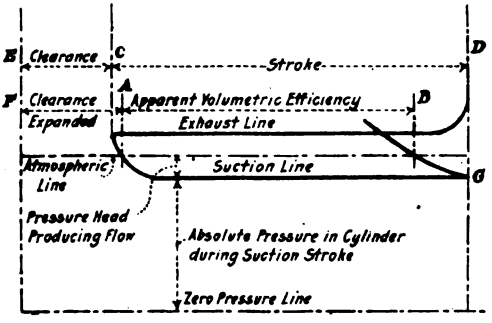

FIG. 11 IDEAL SUCTION CARD

38 The volume of mixture required per stroke for full load can be found as follows: From Fig. 10 the B.t.u. required per hour for full load is 794,200, and 794,200/950 = 836 cu. ft. of gas required per hour, which gives $\frac{836}{60 \times \frac{180}{2}} = 0.1548$ cu. ft. of gas per stroke. Now assuming continuous flow, the time for one stroke being $\frac{1}{6}$ sec., there will be $0.1548 \times 6 = 0.9288$ cu. ft. of gas required per sec. or $(12.5 + 1) \times 0.9288 = 12.53$ cu. ft. of mixture required per sec.

39 The cu. ft. of mixture required for any fractional load can be found in this way, and values for several loads are given in the second column of Table 4.

40 *Pressure in the Cylinder During the Suction Stroke.* Fig. 11 shows a typical full-load suction card for a throttling engine. The difference in pressure between the atmospheric line and the suction line is the head causing the charge to flow into the cylinder.

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41 The piston displacement is 2.73 cu. ft., and as the amount of mixture required for full load is 12.53/6 = 2.09 cu. ft. the true volumetric efficiency is 2.09/2.73 = 76.5 per cent. Column 3 of Table 4 gives true volumetric efficiencies for the assumed loads.

42 At the end of the exhaust stroke the back pressure is about 1.5 or 2 lb., and as the piston moves out on the suction stroke the burned gases in the clearance space must expand down below atmospheric pressure before the new charge can begin to enter the cylinder. If 20 per cent clearance is allowed for the engine under consideration and assuming that expansion takes place isothermally, which is close enough for this small expansion, the burned gases will occupy $v_2 = \frac{p_1 v_1}{p_2} = \frac{(14.2 + 1.8)\ 0.20}{14.2} = 22.5$ per cent of the piston displacement at atmospheric pressure, as shown at FA, Fig. 11.

TABLE 4 DETERMINING AVERAGE PRESSURES IN CYLINDER DURING SUCTION STROKE FOR VARIOUS LOADS

Per cent rated load	Cu. ft. mixture per sec.	True vol. effy., per cent	Initial volume, v_1, per cent	Atmos. press., p_1, lb. per sq. in.	Final volume, v_2, per cent	Average suction press., p_2, lb. per sq. in.
110	13.43	82.2	104.7	14.2	120	12.65
100	12.53	76.5	99.0	14.2	120	12.03
87.5	11.45	70.0	92.5	14.2	120	11.36
75.0	10.35	63.2	85.7	14.2	120	10.65
62.5	9.32	56.8	79.0	14.2	120	9.96
50.0	8.22	50.3	73.8	14.2	120	9.19
37.5	7.15	43.1	65.6	14.2	120	8.63
25.0	6.08	37.2	59.7	14.2	120	7.85

43 From the above it follows that the amount of mixture in the cylinder at the end of the suction stroke if measured at atmospheric pressure would occupy (22.5 + 76.5 =) 99 per cent of the piston displacement, but when it occupies the total volume or (20 + 100 =) 120 per cent of the piston displacement, it exists at some lower pressure p_2 which can be found from the equation $p_1 v_1^N = p_2 v_2^N$ by using a value of N which represents the conditions under which this volume change takes place.

44 As a fresh charge enters the cylinder it expands due to the lower pressure in the cylinder, and this expansion should be accompanied by a temperature drop, but due to coming in contact with the hot cylinder walls and hot gases in the clearance space the tem-

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perature of the charge is raised. The result is an expansion with a decrease in pressure accompanied by a rise in temperature, and therefore the value of N, representing this change, must be less than unity.

45 It will be shown later how the value of N was found from test data to be 0.85. In column 7, Table 4, are given the pressures p_2 at the end of the suction stroke, for the different loads, calculated from the equation $p_1 v_1^{0.85} = p_2 v_2^{0.85}$ as follows:

For full load $p_2 = p_1\left(\frac{v_1}{v_2}\right)^{0.85} = 14.2\left(\frac{99}{120}\right)^{0.85} = 14.2 \times 0.849 = 12.03$ lb.

46 This pressure p_2 is the absolute pressure in the cylinder at the end of the suction stroke as shown at G, Fig. 11. The suction line is practically horizontal in large, well-designed engines except for light loads, and the suction pressure p_2 can be assumed to be constant throughout the stroke without serious error. The difference be-

TABLE 5 DETERMINING PORT AREA FOR ANY FRACTIONAL LOAD

MIXTURE ASSUMED TO BE AIR AT 60 DEG. FAHR. AND 70 PER CENT HUMIDITY; BAROMETRIC PRESSURE, 14.2 LB. PER SQ. IN.

Per cent load	Delivered horsepower	p_1, lb. per sq. in.	p_2, lb. per sq. in.	Head, lb. per sq. in.	Q, cu. ft. per sec.	Port area, sq. in.
110	92	14.2	12.65	1.55	13.43	7.48
100	83.6	14.2	12.03	2.17	12.53	5.63
87.5	73.2	14.2	11.36	2.84	11.45	4.25
75.0	62.7	14.2	10.65	3.55	10.35	3.215
62.5	52.2	14.2	9.98	4.22	9.32	2.48
50.0	41.8	14.2	9.19	5.01	8.22	1.85
37.5	31.4	14.2	8.63	5.47	7.15	1.45
25.0	20.9	14.2	7.85	6.35	6.03	1.041

tween atmospheric pressure and the pressure p_2 is the head causing the charge to flow into the cylinder. These pressure heads are given in column 5, Table 5.

47 *Port Areas.* Knowing the amount of charge which must enter the cylinder, and the head causing flow, the problem is to find the port area necessary to pass the given amount of charge. Flow through the ports is probably somewhere between isothermal and adiabatic conditions, but, after passing through the port the charge comes in contact with the hot walls and hot clearance gases and the temperature rises above the initial temperature. Also, when a full-load charge enters the cylinder the temperature drop through the ports is probably much less than when a light-load charge enters the

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cylinder, first, because the mean temperature of the engine is lower at light loads, and second, because the pressure drop is greater at light loads. The conditions affecting flow through the ports are so complicated and variable that a theoretical analysis of the problem seems impossible. However, by the use of constants obtained from experiments an equation can be developed which fits the condition very well.

48 Beginning with the simple equation $Q = CAV$, the port area

where
$$A = \frac{Q}{CV}$$

Q = cu. ft. of mixture entering the cylinder, measured under atmospheric conditions
V = velocity of gas through ports in cu ft. per sec.
A = port area in sq. ft.
C = coefficient of discharge.

49 The values for Q are given in column 6, Table 5, but the values for C and V must be determined before the equation can be solved. $V = \sqrt{2gh}$, where h = the head in feet of gas necessary to produce the pressure head causing flow. The pressure heads are given in column 5, Table 5.

50 Selecting a value for C. From all the available data on the flow of gases through an orifice in a thin plate, it appears that the coefficient of discharge should lie between 0.5 and 0.8, and as the conditions for flow are very bad in this case the coefficient will naturally approach the lower value.

51 The results of the test described in the first part of this paper were analyzed to determine the actual value of C. Solving the equation $Q = CAV$ for C, where $V = \sqrt{2gh}$, C was found to vary from 0.54 to 1.02 from full load to one-quarter load. When the flow was considered isothermal, values for C varied from 0.625 to 1.58, and when considered adiabatic, from 0.525 to 1.21. These values are unreasonable, as might be expected, and therefore a correction factor must be used with any of these equations.

52 The simple equation $Q = CA\sqrt{2gh}$ will be used and adapted to the conditions. This equation neglects the change of density which takes place, and as density is a function of pressure, the first change that suggests itself is to introduce the pressure ratio, giving the equation $Q = CA\sqrt{2gh\,(p_1/p_2)}$. This change is not theoretically correct but is approximately true. Using this equation and solving for C gives values from 0.5 to 0.77, which seem more rational.

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Velocity of approach and inertia of the moving column of gas influence the flow and are also some function of pressure drop. It was found that when the pressure ratio was introduced outside the radical, giving $Q = CA\sqrt{2gh}\,(p_1/p_2)$, the values of C ranged from 0.462 to 0.574, which seem still more rational. The average of these values gives $C = 0.518$, which was used in the final equation, giving

$$Q = 0.518\,A\,(p_1/p_2)\sqrt{2gh}$$

as an empirical equation for flow of the charge into the cylinder. The equation for port area now becomes

$$A = \frac{Q}{0.518\sqrt{2gh}} \times \frac{p_2}{p_1}$$

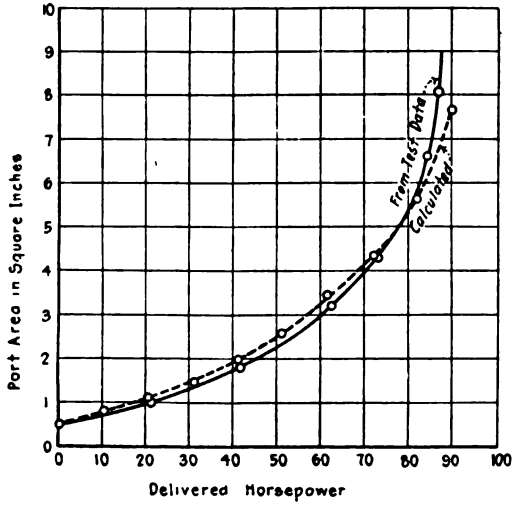

FIG. 12 RELATION BETWEEN DELIVERED HORSEPOWER AND PORT AREA FROM TEST AND CALCULATIONS

from which the port area required for full load is

$$A = \frac{12.53}{0.518 \times \sqrt{2} \times 32.2 \times 4320} \times \frac{12.03}{14.2} = 0.0389 \text{ sq. ft.}$$

or $$(0.0389 \times 144 =)\ 5.63 \text{ sq. in.}$$

53 The port areas for three-quarter, half, and quarter loads were determined in this way and are given in column 7, Table 5, from which the curve in Fig. 12 was plotted. The curve as found from test also appears in this figure and shows the close agreement of the two curves in general form.

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CONCLUSIONS

54 The foregoing work has been done to find out as nearly as possible the conditions under which the charge enters the cylinder of a throttling gas engine, and to suggest a method of supplying for any load the required amount of charge that will tend to make the engine regulate with the same degree of sensitiveness throughout the full range of load. In Fig. 12 there are two curves showing the relation between delivered horsepower and port area; one is based on test data and the other is plotted from calculated data for the same engine. From these curves and the characteristic curve of the governor to be used, the relation between the travel of the governor collar and port area can be determined and a governing mechanism designed which will give equal changes in load for equal movements of the

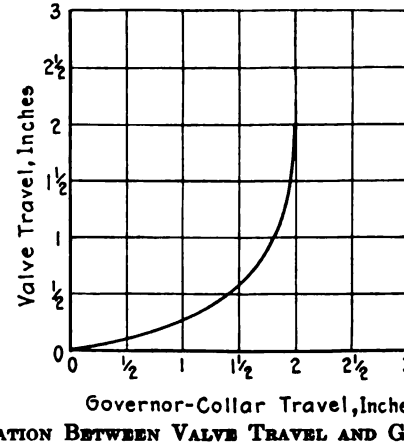

FIG. 13 RELATION BETWEEN VALVE TRAVEL AND GOVERNOR-COLLAR TRAVEL

governor collar. Another way of obtaining the same result would be to so shape the ports that equal changes in governor-collar travel would give equal movements to the valve, but at the same time give the proper port area for equal changes in power delivered. It is possible that for other fuels and types of engines the constants used in working out the above problem may differ slightly, but it is believed that the method can be applied to any case with satisfactory results.

55 Suppose now it is desired to connect a governor with a collar travel of, say, 2 in. to a valve with a travel of 2 in., equal movements of which change the port area by equal amounts. A curve could

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then be drawn as shown in Fig. 13 showing governor-collar positions plotted against valve positions and a suitable connecting mechanism designed to give the desired results.

56 One point to be noted from this test is that while the throttle valve had a travel of 2½ in. the engine carried its rated load with an opening of 1¼ in. and the remaining opening only gave 10 per cent overload capacity. This would seem to indicate that large port areas and low velocities do not increase the capacity of the engine very much. Some of this effect may have been caused by the resistance of the air supply due to the long intake pipe, or probably due to the resistance offered to the charge in passing through the poppet valve, but as the engine gave mean effective pressures of over 100 lb., it was apparently doing about all that could be expected of it.

57 The author is fully aware of the fact that this paper, based on one test only, may have errors in it and is also subject to criticism in places, but it is hoped that it will throw some light on a problem which has been somewhat neglected. In looking up the subject there seemed to be very little material available, and for this reason this paper has been offered to those persons interested in gas-engine design.

APPENDIX

SELECTING A VALUE FOR N

58 The upper curve in Fig. 7 is plotted from test data and shows the relation between apparent volumetric efficiency and absolute pressures in the cylinder. It is known that the apparent volumetric efficiency as found from the low-spring indicator card will be greater than the true volumetric efficiency on account of the increase in temperature of the fresh charge when it comes in contact with the hot cylinder and piston walls and exhaust gases; therefore the curve showing the relation between true volumetric efficiency and absolute pressure in the cylinder will fall below the curve plotted from the test data. The problem is to find how far below it will fall, and to find some relation by which the position of the curve can be determined. Since it is known that the fresh charge expands as it enters the cylinder during the suction stroke, due to its temperature being raised by contact with the hot walls of the cylinder and piston, there will be a pressure-volume change with increase of temperature and this condition can be expressed by the equation $p_1 v_1^N = p_2 v_2^N$, where N has a value less than 1.

59 Ten different volumetric efficiencies were assumed ranging from 0 to 90 per cent, and the pressures were found under which these volumes, plus the clearance volume, would occupy the total volume of 120 per cent. Values for N of 1.3, 1, 0.9, 0.85, 0.8 and 0.7 were used, and the resulting pressures plotted against volumetric efficiencies gave the set of curves shown in Fig. 14.

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60 The light lines represent the calculated curves and the heavy line is the line obtained from test data. It will be noted that the curve plotted with the results obtained by using $N = 1.3$ lies above the test curve through the range of possible cylinder filling. This would indicate that the actual amount of material that entered the cylinder was more than the indicator card accounted for, which cannot be true. The curve resulting from $N = 1$ becomes a straight line and cuts across the test curve at the higher volumetric efficiencies, also the curve obtained from using $N = 0.9$ crosses the test curve at the lower volumetric efficiencies. This would indicate that for heavy loads the real volumetric effi-

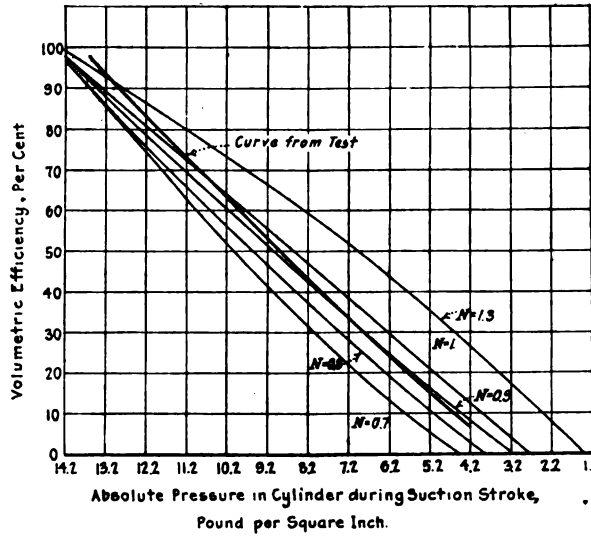

FIG. 14 SELECTING VALUE FOR N IN EQUATION $p_1v_1^N = p_2v_2^N$

ciency or cylinder filling would be less than the apparent filling, while at light loads it would be greater, and this does not seem reasonable.

61 The curves plotted with $N = 0.7$ and 0.8 both fall entirely below the test curve but do not approach it at the lower volumetric efficiencies. The curve resulting from $N = 0.85$ as shown in Fig. 7 approaches the test curve at the low efficiencies and seems to be the correct one to use, since it is apparent that the two volumetric efficiencies approach each other at light loads. It is to be noted that there is very little difference in the curves at the higher points whether we use $N = 1$ or $N = 0.7$, and therefore the lower part of the curve should be used to select N. By using the curve plotted with $N = 0.85$ the ratio of the apparent filling to the real filling is found to be about 1.065 for all loads. This corresponds with the ratio assumed above, and the value of $N = 0.85$ seems to be justified on the basis of reasoning and also by test results.

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No. 1597

A CODE OF SAFETY STANDARDS FOR INDUSTRIAL LADDERS

PRESENTED TO THE SOCIETY BY THE SUB-COMMITTEE ON PROTECTION OF INDUSTRIAL WORKERS THROUGH WILLIAM A. VIALL, WHO PREPARED THE ORIGINAL MATERIAL CONTAINED HEREIN FOR THE SUB-COMMITTEE'S ACTION

NOTE — The word "SHALL" where used is to be understood as mandatory and "SHOULD" as advisory.

DEFINITIONS

The term *Fixed Ladder* as used in these regulations means a ladder that is substantially fastened to a structure in a fixed position.

The term *Portable Ladder* as used in these regulations means a ladder with but one section, which is used transiently at various locations.

The term *Extension Ladder* as used in these regulations means a ladder consisting of two or more parallel sections traveling in guides or brackets so arranged that it may be adjusted to variable lengths.

The term *Portable Step Ladder* as used in these regulations means a ladder so constructed as to be self-supporting.

The term *Fire Ladder* as used in these regulations means a ladder used exclusively for fire purposes.

The term *Trolley Ladder* as used in these regulations means a ladder the movement of which is confined in permanent guides or ways at top or bottom, or both.

The term *Sectional Ladder* as used in these regulations means a ladder consisting of two or more sections so constructed that the sections will telescope into each other.

The term *"A"-Ladder* or *Scaffold Ladder* as used in these regulations means a ladder whose parts, each equivalent to a straight ladder, are hinged at the top to form equal angles with the base.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Received by the Council February 15, 1918, and ordered printed.

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SECTION 1 GENERAL

a Where stairways are not provided, fixed ladders should be used for access to elevated positions; where fixed ladders are not suitable, portable ladders should be used.

b Ladders shall be numbered, or otherwise designated, and regular inspections shall be made of their condition.

c The use of broken or weak ladders, or ladders with missing rungs, is prohibited.

d When defects develop to such an extent that the ladder is to be permanently discarded, it shall be destroyed.

e Side rails, where wood is used, shall be straight-grained. Knots one-half ($\frac{1}{2}$) inch or less in diameter will be permitted when they are in the center of the rails. The following thoroughly seasoned woods should be used: Northern spruce, Oregon pine, Norway pine, yellow long-leaf pine, or Oregon fir.

f Rungs shall be inserted in holes in the side rails and kept from turning, and shall not exceed fourteen (14) inches in length at the top.

g Wooden rungs shall be straight-grained, free from splinters, and absolutely free from knots. The following woods should be used: White ash, white oak (3rd growth), or hickory.

h Steps, where wood is used, should be constructed of the following woods: Northern spruce, Oregon pine, Norway pine, or oak.

i Ladders shall have a uniform step or rung spacing of twelve (12) inches on centers. [Mason ladders having a uniform spacing on centers of ten (10) inches and fire ladders having a uniform spacing of fourteen (14) inches excepted.]

j Ladders shall be equipped with devices designed to prevent slipping. (Fixed ladders, portable step ladders, and "A"-ladders excepted.)

SECTION 2 FIXED LADDERS

Ladders designed to reach safety valves, cut-outs, etc., where speed of operation may mean a saving of life, should always be of a permanent type, securely fastened, and constructed of steel or iron.

a Ladders having side rails are preferred to the type made of U-shaped section embedded in wall or fastened to stack, etc.

b The pitch of ladders shall not be such that a man's position is necessarily below the ladder when climbing.

c Side rails, where metal is used, shall be not less than three-quarters ($\frac{3}{4}$) of a square inch in cross-section. A minimum size of two (2) inches by three-eighths ($\frac{3}{8}$) inch should be used. Where wood is used, they shall be not less than six (6) square inches in cross-

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section and shall be dressed on all sides. A section one and three-quarters (1¾) inches by three and three-quarters (3¾) inches (2 by 4 dressed) would be suitable for this purpose.

d Splice plates, where metal is used, shall be of the same size and material as side rails and shall be double-riveted or -bolted. Bolts or rivets shall be countersunk on inside and shall be not less than one-half (½) inch nor more than five-eighths (⅝) inch in diameter, where cross-section does not exceed that of two (2) inches by three-eighths (⅜) inch. Where wood is used, there shall be splices on outside of side rails and joints shall be double-bolted. Carriage bolts shall be used. All splice pieces shall be chamfered at the ends.

e Rungs should be round. Where solid metal is used, they shall be not less than five-eighths (⅝) inch in diameter; where pipe is used, they shall be of equivalent strength; where wood is used, they shall not be less than one and one-half (1½) inches in diameter and the tenon shall be at least one (1) inch in diameter or its equivalent in strength.

f Distances from front of rungs to nearest permanent object back of the ladder shall be not less than six and one-half (6½) inches. There shall be a space clear of all obstructions in front of the ladder from bottom to top, of at least thirty (30) inches forward and of at least fifteen (15) inches either side of the center line of the ladder. [Ladders equipped with wells (cages) or their equivalent shall be excepted.]

g Ladders over thirty (30) feet in length should be provided with wells, unless the ladder is built in zig-zag sections and provided with platforms between sections.

h Fastenings shall be made of material equivalent in strength to the rails. Fastenings shall be made to wall by building in, by through bolts, or by expansion bolts grouted or leaded. The maximum vertical distance between fastenings or braces shall not be in excess of ten (10) feet.

i Ladders to landing shall extend a distance of at least forty-five (45) inches above the landing, preferably being goosenecked. The rungs may be omitted above the roof. Where a man must step a greater distance than eighteen (18) inches from ladder to roof, tank, etc., a platform shall be provided.

SECTION 3 PORTABLE STRAIGHT LADDERS

a Ladders over thirty (30) feet in length should not be used.

b Side rails shall have a minimum cross-section equivalent in strength to a northern spruce rail of the following dimensions:

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Up to and including 10 ft.	$2\frac{3}{8}$ x $1\frac{3}{8}$ in.
Over 10 ft. up to and including 18 ft.	$2\frac{3}{4}$ x $1\frac{3}{8}$ in.
Over 18 ft. up to and including 26 ft.	3 x $1\frac{5}{8}$ in.
Over 26 ft. up to and including 30 ft.	$3\frac{1}{2}$ x $1\frac{7}{8}$ in.

c Side rails should be spread so that the width of the ladder at the bottom will be greater than the width at the top, preferably by a taper of one-quarter ($\frac{1}{4}$) inch per foot of length.

d Rungs shall be equivalent in strength and wear to an ash rung of the following dimensions:

	Diameter	Tenon
Up to and including 24 in. in length	$1\frac{1}{4}$ in.	$\frac{7}{8}$ in.
Over 24 in. up to and including 30 in. in length	$1\frac{3}{8}$ in.	$\frac{7}{8}$ in.

e Portable ladders should be fully protected at their bases to prevent slipping. For use on wood or earth the bases should be provided with case-hardened steel spurs; or a serrated disk of case-hardened metal, held in position on dowel pins by springs, cotters and nuts, is recommended. These spurs shall be kept sharp. On concrete floors, pivoted shoes with lead or carborundum faces may be used.

f When used on iron floors an attendant should be placed at the foot of each ladder.

g Whenever possible to use ladders with a gooseneck or hook at the top, these should be provided, as forming the best protection against accident.

SECTION 4 EXTENSION LADDERS

a Table 1 should be followed in the construction of extension ladders.

b Ladders should be equipped with safety locks.

SECTION 5 FIRE LADDERS

a The construction, use and maintenance of industrial fire ladders shall conform to the specifications herein set forth covering portable straight ladders (Section 3, Par. *a* excepted).

b A uniform step or rung spacing of fourteen (14) inches shall be used.

c Fire ladders should be painted red and shall be plainly marked "For Fire Purposes Only."

d Fire ladders shall not be used for any other purpose than that for which they are intended.

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TABLE 1 CONSTRUCTION OF EXTENSION LADDERS

Side Rails:

Up to and including 44 ft. long: Material, Norway pine, clear and straight-grained, free from knots.
48 ft. to 60 ft. long: Material, Oregon fir, clear and straight-grained, free from knots.

Rungs:

Material: Oak, ash or hickory, straight-grained, free from knots, and live and tough.
Dimensions: 1¼ in. diameter at center; taper to 1⅛ in. diameter, straight-turn to ⅝ in. diameter for holes in side rail.

Ladder Dimensions

Length, ft.	Dimensions of side rails (cross-section same at both ends), in.	Distance between side rails, top section, in.	Distance between side rails, bottom section, in.	Vertical distance between rungs, in.
20, 22, 24, 26	2½ x 1½	12½	14½	12
28	2½ x 1½	14½	17	12
32, 36	2½ x 1⅝	14	17	12
40	3½ x 1⅝	15½	18½	12
44	3½ x 1⅝	17½	20½	12
48, 52	3½ x 1½	17½	20½	12
60	3½ x 1½	18	21½	12

SECTION 6 PORTABLE STEP LADDERS

a Ladders over twenty (20) feet in length shall not be used.

b Side rails shall have a minimum cross-section equivalent in strength and wear to a northern spruce side rail of the following dimensions:

Up to and including 12 ft..... ⅞ x 3 in.
Over 12 ft. up to and including 16 ft..... 1 x 3½ in.
Over 16 ft. up to and including 20 ft..... 1 x 4 in.

c Front and back rails shall be so spread when the ladder is open that the spread at the bottom, inside to inside, shall be greater than the spread at the top, inside to inside, by an amount equal to or greater than one and one-half (1½) inches per foot of length of ladder. Minimum width between side rails at the top step, inside to inside, shall be not less than twelve (12) inches, with a taper of at least one (1) inch per foot of length of ladder.

d Steps shall be equivalent in strength and wear to a northern spruce step of the following dimensions:

Up to and including 12 ft..... ¾ x 4½ in.
Over 12 ft. up to and including 16 ft..... ⅞ x 4½ in.
Over 16 ft. up to and including 20 ft..... 1 x 4½ in.

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e Steps shall be trussed and screwed or bolted to the side rails. Nails shall not be used as sole fastenings.

f An automatic locking device to hold the front and back rails securely in position shall be an integral part of each ladder.

SECTION 7 "A"-LADDERS OR SCAFFOLD LADDERS

a Ladders over twenty (20) feet in length should not be used.

b Side rails shall have a minimum cross-section equivalent in strength and wear to a northern spruce rail of the following dimensions:

Up to and including 12 ft.	$1\frac{1}{4}$ x $2\frac{3}{4}$ in.
Over 12 ft. up to and including 16 ft.	$1\frac{1}{2}$ x 3 in.
Over 16 ft. up to and including 20 ft.	$1\frac{1}{2}$ x $3\frac{1}{2}$ in.

c Side rails shall be so spread that the width of the ladder at the bottom, inside to inside, shall be greater than the width at the top, inside to inside, by an amount equal to or greater than one and one-half ($1\frac{1}{2}$) inches per foot of length of ladder.

d Supports shall be equivalent in strength and wear to an ash bearing one (1) inch by two (2) inches. They shall be straight-grained and absolutely free from knots, shall have tenons not less than five-eighths ($\frac{5}{8}$) of an inch by two (2) inches, secured in place with wire nails. They shall be not less than three (3) inches from the top of the side rails. They shall be eighteen (18) inches on centers, and shall be staggered. The tops of side rails shall be cut on a bevel to prevent them from spreading. Hinges shall be wrought or malleable iron, bolted or riveted to side rails.

SECTION 8 TROLLEY LADDERS

a Ladders shall be suspended from tracks fastened securely to the ceiling or to the framework with which the ladders are connected. Tracks should be of wrought iron or wood, and should be tested to double the maximum of load for marginal safety. Tracks shall be constructed so that it is impossible for the wheels to jump the track, by having the wheels in pairs situated on opposite sides of a vertical flange or by having the track so shaped that it completely encloses the sides of the wheels. The extreme front and back wheels shall have a horizontal distance of at least eighteen (18) inches between their centers.

b The track wheels shall be rigidly fastened to the top of the ladder with suitable steel or wrought-iron brackets. These brackets may be fastened to a bolt connecting the two side rails of the ladder or to the top step. In the latter case the top step shall be provided with extra metal braces to the side rails.

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c Side rails shall have a minimum spread, inside to inside, of ten (10) inches.

d Side rails shall have a minimum cross-section equivalent in strength and wear to a northern spruce side rail three and one-half ($3\frac{1}{2}$) inches by seven-eighths ($\frac{7}{8}$) inch.

e Steps shall be equivalent in strength and wear to a northern spruce step four and three-quarters ($4\frac{3}{4}$) inches by three-quarters ($\frac{3}{4}$) inch.

f Steps, where metal is used, shall be flanged downward not less than two (2) inches at both ends and secured by two bolts or rivets to each side rail. Where wood is used, they shall be inset in the side rails one-quarter ($\frac{1}{4}$) inch, glued and nailed; all, or at least alternate steps, shall be braced to the side rails with metal brackets placed under the steps.

g The base of the ladder shall rest on two wheels or casters.

h A clamp or lock should be provided to hold the ladder immovable while it is in use at any location.

SECTION 9 SECTIONAL LADDERS

a The bottom section shall be six (6) feet in length and shall have a minimum spread between rails at the base, inside to inside, of twenty-one (21) inches.

b Sections (intermediates) shall be six (6) feet in length and shall have a minimum spread between rails at the bottom, inside to inside, of thirteeen (13) inches.

c The top section may converge with a minimum spread between rails at the bottom, inside to inside, of thirteen (13) inches.

d Side rails shall have a minimum cross-section equivalent in strength and wear to a northern spruce side rail of the following dimensions:

Up to and including 5 sections	$2\frac{3}{4} \times 1\frac{1}{8}$ in.
Over 5 sections	$3\frac{1}{8} \times 1\frac{1}{8}$ in.

e Rungs shall be equivalent in strength and wear to an ash rung one and three-sixteenths ($1\frac{3}{16}$) inches in diameter with seven-eighths ($\frac{7}{8}$) inch tenon.

SAFE PRACTICES

Use care in placing portable ladders before using them. If there is danger of ladder's slipping, have some one hold it. Do not place ladders too straight or at too great an angle, or they may fall, break or slip.

Never place ladders in front of doors opening toward the ladder.

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Ladders should never be placed against window sashes. Screw a board across top of ladder to give bearing at each side of window.

Step ladders should be fully opened and locked in all cases before any one steps on them.

Always face ladder when ascending or descending.

Do not go up or down a ladder without free use of both hands. If material has to be handled, use a rope.

Never slide down a ladder.

Never use broken or weak ladders or ladders with missing rungs.

When defects of construction develop to such an extent that the ladder is discarded, it should be destroyed.

Ladders withdrawn from service for repairs should be sent to the repair shop or tagged as "Dangerous — DO NOT USE."

See that ladders you use have safety feet, and, where necessary, safety hooks at top.

Short ladders should not be spliced together, as they are not strong enough to be used as long ladders.

Safe practice demands that ladders be numbered, classified and subjected to careful and periodic inspection. Ladders should be kept clean and free from dirt or splashings of paint or material. Imperfections or defects are not readily observed unless ladders are kept in good condition.

Iron and steel ladders should be coated with a preservative paint or composition. Wooden ladders, if used out of doors, should also be carefully treated with a suitable preservative.

A satisfactory practice is the storing of ladders upon brackets by arranging them against wall in such manner as to permit inspection without moving ladders.

Storage of ladders involves a separate problem. Shelter should be provided in all cases. If placed upright, 75 degrees will afford a safe angle; if racks are used, place the ladder on edge rather than flat; this will prevent trouble and danger of accident in withdrawing the ladder for use.

Safety belts and hooks should be provided when the character of the work demands the attention of the workman or constitutes an element of danger.

Respectfully submitted,

JOHN PRICE JACKSON, *Chairman*
JOHN H. BARR
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SUB-COMMITTEE ON PROTECTION OF INDUSTRIAL WORKERS

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No. 1598

A CODE OF SAFETY STANDARDS FOR POWER-TRANSMISSION MACHINERY[1]

RULES AND REQUIREMENTS FOR THE PROTECTION OF INDUSTRIAL WORKERS FROM HAZARDS COMMONLY PRESENTED BY MECHANICAL EQUIPMENT USED FOR TRANSMITTING AND DISTRIBUTING POWER FROM THE PRIME MOVERS TO THE VARIOUS POWER-UTILIZING MACHINES, TOOLS AND DEVICES

NOTE. — The use of properly designed, constructed and installed individual motor-driven equipment with electrical power distribution not only eliminates many of the hazards demanding this Code, but also gives an uninterrupted distribution of natural and artificial light, and a greater flexibility and range of speeds than is possible with mechanical power-distributing systems.

The following specifications describe standard guards for all power-transmission equipment hereinafter mentioned, and apply to all main shafting, jack shafting, drive shafting and countershafting, and their belts and other attachments up to but not including belts actually driving machines.[2]

2 *Class A Guards:* If the clearance between the guard and the guarded part is less than five (5) inches, a metal guarding material that will not admit objects larger than one-half ($\frac{1}{2}$) inch in diameter, strong enough to withstand loads to which it may be subjected, durable enough to withstand ordinary wear and tear, substantially fabricated and erected, and free from sharp points and edges.

[1] Compiled and presented by Carl M. Hansen and Rufus W. Hicks, under the direction and with the approval of the Committee on Health and Safety, National Association of Manufacturers. Submitted by the Sub-Committee on Protection of Industrial Workers for the consideration of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

[2] Belts actually driving machines will be considered "machine belts," and therefore a subject for machine codes.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Received by the Council February 15, 1918, and ordered printed.

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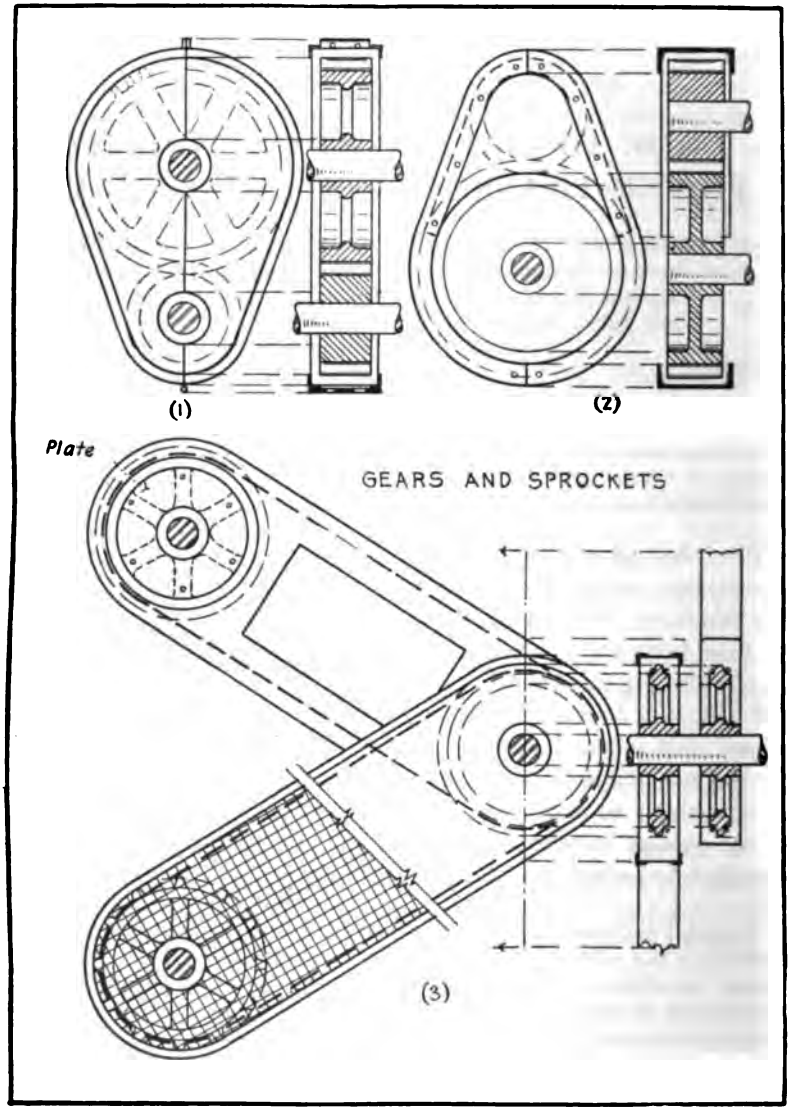

FIGS. 1 TO 3 GUARDS FOR GEARS AND SPROCKETS

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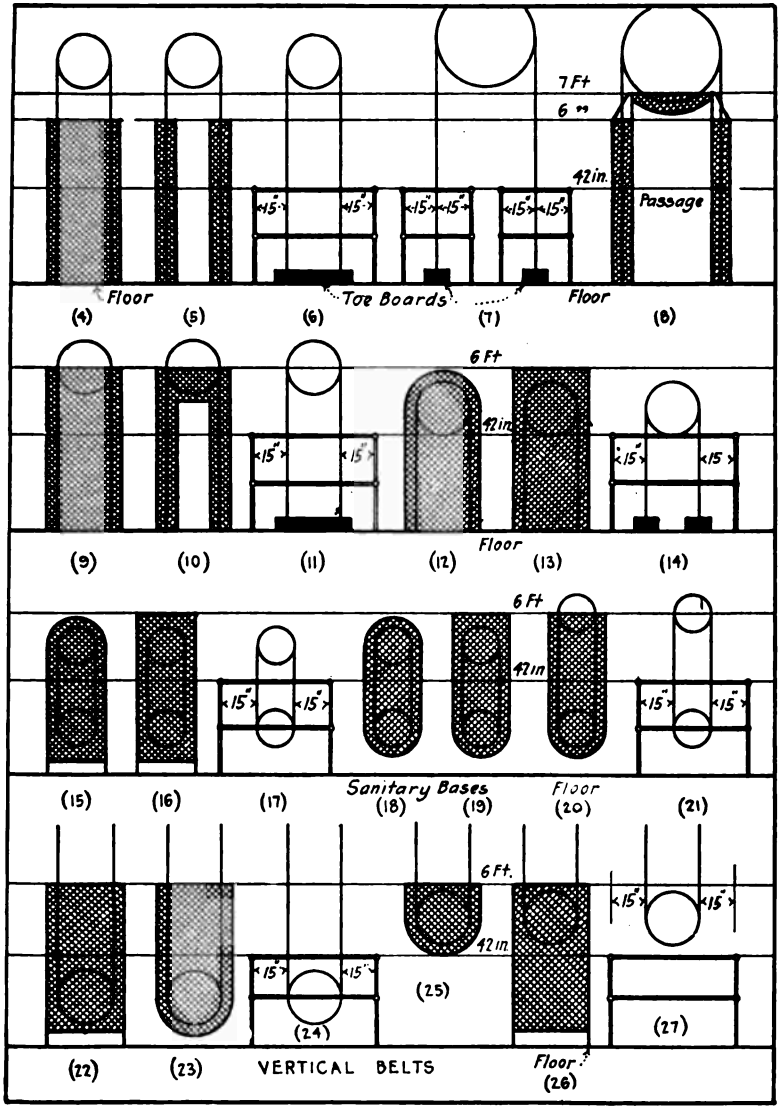

FIGS. 4 TO 27 GUARDS FOR VERTICAL BELTS

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3 *Class B Guards:* If the clearance between the guard and the guarded part is five (5) inches or more, a metal guarding material that will not admit objects larger than two (2) inches in diameter, strong enough to withstand loads to which it may be subjected, durable enough to withstand ordinary wear and tear, substantially fabricated and erected, and free from sharp points and edges.

4 *Handrails:* If the clearance between the guard and the guarded part is fifteen (15) inches or more (measured horizontally from extreme parts within six (6) feet of floor), a handrail forty-two (42) inches in height with at least one intermediate rail, supported at least every eight (8) feet, of substantial and rigid construction and erection, with no sharp points or edges.

5 If constructed of pipe, the rails and posts shall be at least equal in strength to one and one-fourth (1¼)-inch standard-weight pipe.

6 If constructed of structural metal, the rails and posts shall be at least equal in strength to two by two by one-fourth (2 x 2 x ¼)-inch angles.

7 If constructed of wood, the top rail shall be two inches by four inches (2 x 4), the center rail not less than one inch by four inches (1 x 4), and the posts four inches by four inches (4 x 4), all straight-grained lumber dressed on four sides, or other construction of equal strength.

8 *Toe Boards.* When power-transmission equipment extends through floors or into pits, Class A and B guards shall extend to the floors or toe boards six (6) inches in height shall be provided around the floor opening in addition to standard handrails. (See Figs. 6, 7, 11, 14, 30, 31, 34, 48.)

9 *Sanitary Bases.* Class A and B guards, for power-transmission equipment not extending through floors, shall enclose all exposed sides to two (2) inches below the bottom of the lowest moving part when the clearance between that part and the floor is less than eight (8) inches; or when the clearance between the lowest moving part and the floor is eight (8) inches or more, the guards shall be closed on the bottom, or extended on all exposed sides down to six (6) inches above the floor. (See Figs. 15, 26, 36–40, 42, 43, 49–54.)

10 *Gears and Sprockets.* All power-driven gears and sprockets shall be completely enclosed on exposed sides with standard guards as specified in Class A or B, except in cases where the design and operation of the parts to be guarded make a complete enclosure clearly impractical; in which case the face of the gears or sprockets shall be

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covered with a band guard surrounding all exposed teeth, with flanges on both sides extending inward beyond the roots of the teeth, and there shall be a continuous smooth web cast or fitted between the hubs and rims of the gears or sprockets. (See Figs. 1, 2, 3.)

11 *Vertical and Inclined Belts, Ropes, Chains.* All vertical and inclined belts, ropes and chains used for transmitting or distributing power (except belts traveling less than 120 feet per minute, or transmitting so little power that accidental contact therewith could cause no accident) shall be provided with standard guards as specified in Class A or B, six (6) feet high on exposed sides, or on exposed sides and top, or with a standard handrail on exposed sides. (See Figs. 4 to 46, inclusive.)

12 *Horizontal Belts, Ropes, Chains.* All horizontal belts, ropes and chains used for transmitting or distributing power (except belts traveling less than 120 feet per minute, or transmitting so little power that accidental contact therewith could cause no accident) shall be guarded as follows:

13 *Low Belts.* If the upper part of the belt is lower than six (6) feet above the floor or working platform, it shall be provided with standard guards specified in Class A or B, six (6) feet high on exposed sides, or on exposed sides and top, or with a standard handrail on exposed sides. (See Figs. 47–50.)

14 *Medium Belts.* If the upper part of the belt is higher than six (6) feet above the floor or working platform and the lower part of the belt is lower than six (6) feet above the floor or working platform, it shall be provided with standard guards as specified in Class A or B, six (6) feet high on exposed sides, or with a standard handrail on exposed sides. (See Figs. 51–58.)

15 *High Belts.* If the lower part of the belt is higher than six (6) feet above the floor or working platform and lower than seven (7) feet above the floor, it shall be provided with standard guards as specified in Class A or B, on exposed sides and bottom, or with standard handrail on exposed sides. (See Figs. 59, 60.)

16 *Belts over Driveways.* Where a horizontal belt is located over a driveway or passageway the highest floor of any wagon or truck passing beneath the belt shall be considered a working platform.

17 *Belt Fasteners.* All belts not provided with guards as specified in Class A or B and within seven (7) feet of the floor or working platform shall be free from metal lacings and metal fasteners.

18 *Belt Shifters.* Belt shifters shall be provided for all tight- and loose-pulley belts, and shall be so designed and constructed that

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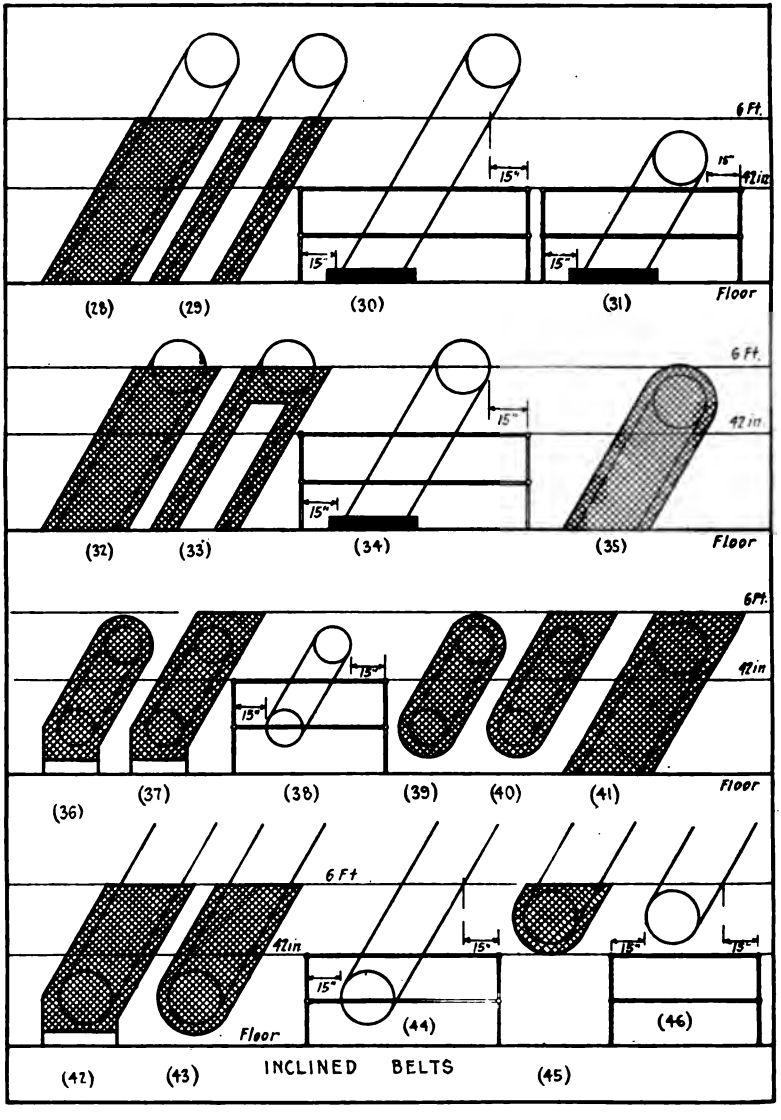

FIGS. 28 TO 46 GUARDS FOR INCLINED BELTS

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ordinary vibrations or accidental contact will not alter the set position, and shall have a controlling handle conveniently located. (See Figs. 61–63.)

19 *Pulleys.* Pulleys belted from above or from the side in such a way as to allow passage beneath the pulley, and within seven (7) feet of the floor or working platform and not completely enclosed by standard belt guards or handrails, shall be guarded to the top of the pulley or to a height of seven (7) feet above the floor or working platform on exposed sides and beneath by guards as specified in Class A or B, or be enclosed on exposed sides by standard handrails. (See Figs. 64–67.)

20 *Bearing Clearance.* The clearance on shafting between pulleys and bearings or between pulleys and fixed objects shall be not less than thirty-six (36) inches and wider than the belt, or the pulleys shall be guarded on the near side with stationary guards as specified in Class A or B, and all revolving objects in the clearance shall be smooth, cylindrical and concentric with shafting. No guard shall be required when a runway is installed. (See Figs. 68–73.)

21 *Belt Clearance.* The clearance on shafting between pulleys and pulleys, collars, couplings or other revolving attachments shall be wider than the widest belt used, or the pulleys shall have flanges or guards to prevent the belt from dropping into the clearance. (See Figs. 68–73.)

22 *Abandoned Pulleys.* Pulleys without belts shall be guarded as though belted, or removed from revolving shafts.

23 *Clutches.* Friction clutches, jaw clutches and compression clutches within seven (7) feet of the floor or working platform or within thirty-six (36) inches of a bearing shall have their operating mechanism completely enclosed in stationary guards as specified in Class A or B, or in smooth, concentric revolving guards of solid construction with no projecting parts or attachments.

24 *Couplings.* All couplings within seven (7) feet of the floor or working platform or within thirty-six (36) inches of a bearing shall be guarded as follows:

25 *Rigid Couplings.* Sleeve couplings, flange couplings and clamp couplings shall be cylindrical and concentric with the shafting and with no parts or attachments projecting beyond the largest periphery of the coupling or its projecting flanges. (See Figs. 74, 75.)

26 *Flexible Couplings.* Flexible and universal couplings shall be completely enclosed in standard stationary guards as specified in

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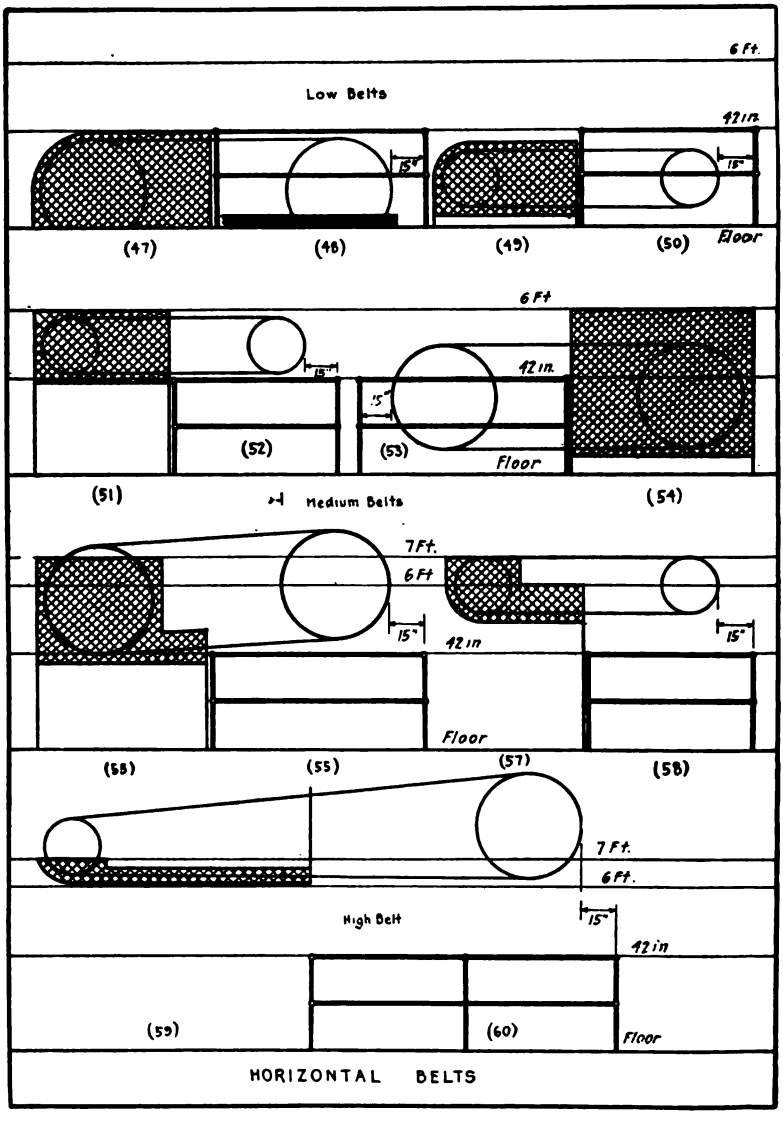

FIGS. 47 TO 60 GUARDS FOR HORIZONTAL BELTS

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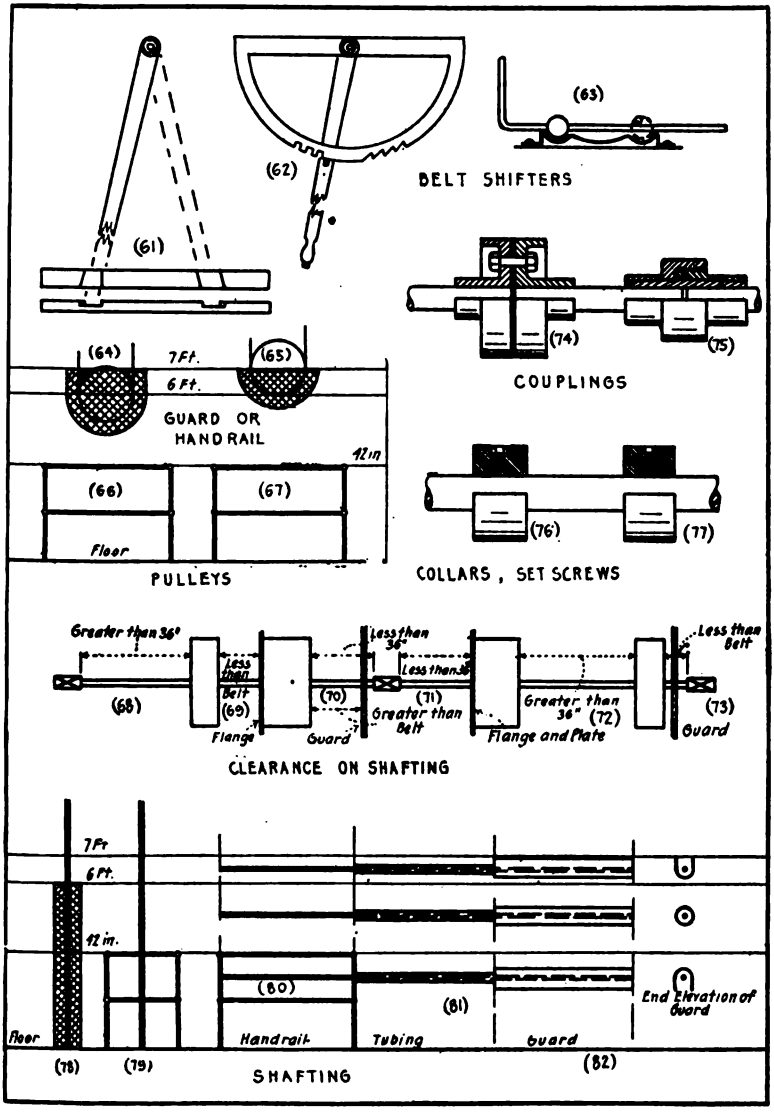

FIGS. 61 TO 82 GUARDS FOR MISCELLANEOUS EQUIPMENT

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Class A or B, or in smooth concentric revolving guards of solid construction.

27 *Clamp Couplings* which are of irregular shape or unknown strength are prohibited on revolving shafting.

28 *Collars.* Assembled collars shall be smooth, cylindrical and concentric with shafting, with no projecting parts or attachments. (See Figs. 76, 77.)

29 *Set Screws.* All set screws in revolving parts not enclosed by standard guards as specified in Class A or B shall be flush with or countersunk below the periphery of the part retaining the set screws. (See Figs. 76, 77.)

30 *Keys.* All keys or keyways in revolving shafting not enclosed by standard guards as specified in Class A or B shall be made flush with the end and periphery of the shaft or enclosed by smooth, cylindrical concentric guards.

31 *Vertical Shafting.* Vertical shafting with or without collars, couplings, clutches, pulleys, or other attachments shall be enclosed on exposed sides with standard guards as specified in Class A or B to a height of six (6) feet above the floor or working platform, or with a standard handrail. (See Figs. 78, 79.)

32 *Horizontal Shafting.* Horizontal shafting with or without collars, couplings, clutches, pulleys, or other attachments, including dead ends, within seven (7) feet of the floor or working platform, shall be enclosed on all exposed sides with standard guards as specified in Class A or B or with standard handrail, or with freely revolving tubing. (See Figs. 80–82.)

33 *Shafting over Driveways.* Where horizontal shafting is located over driveways or passageways, the highest floor of a wagon or truck passing beneath the shafting shall be considered a working platform.

34 *Emergency Stop Stations.* A station or stations shall be provided in each room, section, or department to stop quickly all power-transmission equipment therein. Such station or stations shall be properly marked and easily accessible and provided with means for locking in "stop" position.

35 *Bearings.* Where possible, bearings shall be of a self-oiling type with reservoir capacities for at least 24 hours' running or shall have other methods of oiling which do not bring the oiler in the danger zone, and shall have necessary drip cups and pans securely fastened in position.

36 *Lubrication.* Oiling which brings the oiler in a danger zone

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shall be done only by an authorized person, and while the machinery is not in motion.

37 *Oiler's Clothes.* The oiler must not wear loose or flowing clothing.

38 *Oiler's Lock.* The oiler shall be provided with a lock and key or with a key to the locks at the emergency stop stations, and with a warning sign to display at the stations when at work on machinery controlled by that station. He shall be required to lock the station in a "stop" position and display the sign before going to work, and unlock and remove the sign when the work is completed and all men have left dangerous places.

39 *Starting Signals.* Ample notice should be given by means of an effective alarm or signal in all departments before power-transmission equipment is started. An effective signal system should be required in all plants where machinery is in group drive, and fixed rules should be established for the use of these signals.

40 *Inspection.* All power-transmission equipment should be carefully inspected at frequent and regular intervals by foremen or authorized inspectors, and defective equipment should be reported for repair and records kept of inspections.

41 *Repairs and Adjustments.* Repairs and adjustments to power-transmission equipment or guards therefor shall be made only when the power is cut off from that equipment, and guards shall be replaced in protective position before the power is cut on.

42 *Removing Guards.* Guards installed in accordance with this Code shall not be removed or rendered ineffective except for repairs spoken of in Par. 41.

Respectfully submitted,

JOHN PRICE JACKSON, *Chairman*
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SUB-COMMITTEE ON PROTECTION OF INDUSTRIAL WORKERS

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No. 1599

THE HUMAN POTENTIAL IN INDUSTRY

By Dr. Otto P. Geier,[1] Cincinnati, Ohio
Non-Member

FOR the past three years history has been writing the terrible story of the human potential in modern war. As a result of a long period of peace, we Americans had looked upon war as a most remote possibility, attested to most strikingly by our present state of utter unpreparedness. As we reflect, it appears now we were not measuring nations by their fighting strength, but rather by their social, industrial and commercial strength. Nations were tabulated for their rate of production and consumption. This differential had its social as well as its economic effect. It produced state and private wealth. It produced leisure, the arts, extended educational and health measures, and raised the standard of living. In brief, the world was in keen competition not only in business life but in social life. Nations were striving to outdo each other in promoting financial success, health and happiness for their people. Individualism had reached its zenith and the philosophy of collectivism was just appearing above the horizon.

It was rather our subconscious minds that recognized the great sea power of England and the militaristic spirit of Germany. Our real attention was focused, not on the plans and intrigues of governments, but rather on the national characteristics of their peoples. We thought of London as the financial center of the world, of the Englishman as the world traveler, a lover of outdoor life and sports, and educated gentleman and judge of the fine arts.

When we traveled in Germany we admired her order and cleanliness, her *Gemüthlichkeit.* The world paid homage to her philosophers, revered her musicians, studied and copied her educational systems and longed for her thoroughness and scientific capacity.

[1] Cincinnati Milling Machine Company.

Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of The American Society of Mechanical Engineers.

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POTENTIAL OF WAR

But the bloody struggle of the past two years has changed our viewpoint of these nations. War, with all its horrors, its terrors, has changed these peoples. The human potential of nations is no longer directed at the creation of comforts, contentment and health, but the backs are bending low under the struggle of destruction of property and life. National efficiency is now expressed in new terms.

Shortly after the program for the Spring Meeting of this Society began to take form, our country entered the war. There were those who doubted the advisability of holding the meeting. Our fearful unpreparedness produced a public state of mind akin to hysteria. We have scarcely had our sober, serious second thought. Democracy is being subjected to the acid test. There are few so daring as to prophesy what failures and what successes we shall find. Of one thing we see signs. Our nation is finding itself. We are trying to forget and forgive ourselves for our "spread eagle" and forget our jingoism. Even in the early stages of preparedness we are intensively appreciating, as never before, the stuff that other nations are made of. Their capacity to produce, their silent ability to suffer, sets us to wonder.

AMERICA REBORN

Perhaps for the first time since the Civil War we are thinking together. Our national consciousness has been reborn. The pettiness in us is disappearing and true Americanism is coming to the foreground. Our faces are turned to the common enemy. We have turned our backs on the paltry bickerings of the past. We are witnessing the first truce in the century-old strife between labor and capital.

This is a day that calls for statesmen as well as soldiers, for calmness as well as courage, for patience and patriotism, for virtue and vigor, for faith and faithfulness, for health as well as willingness to die. This day calls for social reconstruction as well as enemy destruction. Huge is the task in which *all* should find a place to do with all their hearts.

POTENTIAL OF INDUSTRY THE POTENTIAL OF THE NATIONS

And what tasks has our entering the war brought to industry? Huge production? Yes! But is that all? Have not old truths as to the value of the conservation of labor taken new form, new em-

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phasis? Has not The Human Potential in Industry in the nations abroad finally been the measure of their potential on the battlefield? Has the interdependence of man ever been more fully demonstrated? Has the mutual dependence of labor and capital ever been so strikingly proved? Have we ever witnessed such limitless industrial energy and output? Has it occurred to all of us Americans that Europe's industrial experience of the past three years holds not only a lesson but a warning? Militant and efficiently industrial England of war times will be succeeded by industrially militant England of peace times. Labor and capital in England, Germany and in France, having learned the mutual advantage of coöperation in war, are not likely to give up this advantage and return to the destructive internal warfare of former days.

OUR NEW COMPETITION

The question that presents itself is this: Can we keep pace with them in war, and will we keep pace industrially after the war? Can we stand this new type of competition unless we likewise enter upon the program of the new social order? Will not the programs of our National Association of Employers, chiefly defensive in the past, necessarily become socially constructive? Will not labor now have to seek leadership capable of best adjusting itself to these forward-looking steps?

FORWARD-LOOKING INDUSTRY

War has lifted the discussion of "the human potential in industry" out of the realms of philosophy and has used it as the foundation stone of a national economic policy. The Council of National Defense has appointed a committee on the conservation of the health and welfare of the worker, and in the interest of the health and productiveness of labor proposes to establish definite standards of plant operation. The human potential of the nation is needed at its maximum, for the country cannot afford the usual labor losses due to accident, disease or fatigue, and industrial poisoning.

A right-minded, forward-looking man does not wait for compulsory legislation to develop his business organization to the highest degree of efficiency. This type of man, for years, has developed not only the administrative and technical divisions of his plant, but, when most successful, has given a great deal of thought to the human equation: the giving of happiness and meting out of justice to his employees. It has been a great satisfaction to him to find an eco-

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nomic method of lessening the human waste due to preventable accidents and occupational diseases. He noted that a healthy, contented employee was a more productive employee, who, in turn, was a higher type of citizen, demanding a better standard of living for himself and family, better protection for his children against disease, delinquency, and crime, and higher forms of community recreation. He recognized that right in his plant he could make his best contribution to the health and well-being of the worker, and that he had found, perhaps, the most tangible basis for coöperation between himself and his employees. To him it was apparent that by intensively studying the health of his workers he was establishing some splendid new points of contact between himself and his men.

MASTER AND MAN, THEN AND NOW

Industry must find a substitute for the valuable relationship of master and man which passed with the coming of greater industrial concentration. Then the master was teacher as well as craftsman, and to a large degree a substitute for our modern continuation school, manual training and coöperative university engineering course. Master and man worked elbow to elbow. The master largely molded the thought and living of the man. Then they had real personality for each other. Now, in too many instances, the pay envelope expresses the only bond between the two. The man was graduated from his apprenticeship, frequently to set up a business of his own; now, industrial concentration practically hinders the establishment of the new small unit. Then, labor took part in the making of the mechanism and conceived the full purpose of the machine which he assisted the master in building; now, his work is more repetitive and limited to single parts of a machine, whose mechanism he may not understand.

TENEMENTS, STRIKES, LOCKOUTS

It was but natural that in this evolutionary process of industry, capital and labor should become more estranged. They not only worked farther apart, but lived farther apart, for with industrial concentration, community life changed, and the tenement district developed. The difference in their scale of living was more evident. Industrial discontent was more readily bred. Labor and capital organized themselves to meet strife, and strikes and lockouts were the natural outgrowth.

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Neither master nor man can be held accountable for these unfortunate conditions, which were but the natural consequence of industrial evolution and the consequent crowding of population in cities. So engrossed were both labor and capital in adjusting themselves to the new conditions that the estrangement of these former partners in work came on quite unnoticed.

DISTRUST OF EARLY WELFARE WORK

Some years ago industry began to recognize its social obligation. It saw the economic advantage of substituting fine, light, well-ventilated buildings for the dark, unsanitary workshops of the good old days. It was at about the same period that many abortive attempts at so-called welfare work were started, which in most instances failed to make any real contribution to the better understanding of labor and capital. This sort of welfare work was established on purely paternalistic lines, was imposed upon the group of workers without their desire or consent, and all too frequently furnished that for which they had no real need. This type of welfare contributed to the social and superficial requirements of the man, and overlooked the fundamentals. It did not take into account the basic principle that the workman is very human, and that to get the best results out of any socializing effort you must first engage his coöperation. You must put him to work, so that he, too, may use his creative instincts and enjoy with the employer the fruits of intelligent coöperative work. Welfare work of the former kind deserved failure and did fail. It was "built upon the sands" and was all too frequently washed away by the least wave of discontent among the workers. After the first strike, the returning man found the doors of the dining rooms, libraries, and club rooms closed upon him. The whole structure was weak and crumbled at the mere sign of a storm. Is it any wonder then that welfare work came into such disrepute with the worker and was so continuously and effectively used by the labor agitator?

BUILDERS OF MEN

It would indeed be a foolhardy individual who should attempt to interest the members of these organizations in that kind of welfare work. I am equally sure that most of the plants represented by this conference are already engaged in some effort to solve the great problem of human potential in industry. We are all groping our way toward finding the right method. If we can evolve a sound

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economic scheme for the establishment of a human-service department in industry, which day by day will pay dividends, which will reduce lost time for illness and accidents, reduce labor turnover, and quicken loyalty, we will not build up a "block house" which will fall to pieces at the first sign of industrial strife. It will each day have served its purpose, secured a result worth while for itself, and will automatically, along with all other departments, be again set in motion the moment that the wheels of industry begin to turn.

I have faith in big industry. I believe that when builders of big enterprises sense their social opportunities they will also prove themselves to be builders of men. In time their widened perspective will include an active interest in national and local health problems, they will, for the sake of the men, use their good offices for better housing and transportation facilities. They will apply themselves to the great human problem of taking much of the drudgery out of work. With this new purpose in life will come a recompense which cannot be valued in mere dollars.

They will be instituting the first intelligent effort toward the alleviation of poverty and the establishment of social justice. Philanthropy and legislative effort to correct conditions have failed lamentably.

BUILD UPON HEALTH

The activities of the human-service department should be founded on intensive health work. Health is our most vital possession. The mere act of conserving the health is ennobling. Healthy bodies promote right thinking, right living, good habits, and it is upon such factors that intelligence, stability and loyalty are engendered. Unless we have these things, our employment departments, struggling with the labor turnover, our mutual-benefit societies and loan associations, our restaurants, our coöperative buying, our sanitary measures, will meet with but half of the deserved success.

ALL-DAY DISPENSARY

The point of approach to the human potential had best, therefore, be through the industrial dispensary. Under a high-grade physician it will be the great melting pot of the human experiences of men. Here the virtues and the weaknesses of the men will be most apparent. The physician will also be confessor, adviser, priest. Through him the employee may learn that it pays to be healthy,

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steady, and of good habits. He does not hesitate to preach the "Sober First" campaign.

An industrial dispensary, with a dental clinic as its adjunct, will advertise itself. It will come in daily contact with five per cent of the force, the equivalent of the whole force each month. To respond to all the possible services that grow out of these frequent contacts, it will require one full-time physician to every 750 employees.

The men will first use this department for their slight cuts and accidents; next they will begin to call the doctor's attention to some surgical defect with which they have been suffering.

DOUBLING WAGES

I recall the case of an Italian watchmaker with five children, whose complexion was pale and pasty. He seemed anxious to please his foreman, but his work, like his skin, remained rather pale. He had a bad record for absence and lateness. His average earnings amounted to $13 per week. Investigation showed that he had been suffering with hemorrhoids for twenty years and had been repeatedly advised against an operation. He had enough confidence in the plant physician to undergo the operation. As a result, his physical efficiency was raised, so that now his premium earnings are nearly as great as his weekly wages formerly were. In other words, the operation had practically doubled his wages. An inefficient man, an active candidate for the human scrap heap, one whose family had been on the poverty line for years, has been converted into a happy, productive citizen.

In an industrial all-day dispensary men will frequently learn that while they have been treated for rheumatism on the outside, they are actually suffering from broken arches. Again and again men will be found who are continually taking headache dope for headaches due either to gastric conditions or eye strain. Untold numbers of men will be found whose working capacity has been below normal; whom employers have always felt more or less sorry for and therefore did not discharge because they seemed anxious to make good, but they never quite "reached." Quite a lot of these will be found suffering with chronic intestinal toxæmia, while fully as many will be discovered whose lowered vitality has been induced by years of bad mouth hygiene, abscessed roots and pyorrhea. I am thinking just now of such a man who had been treated for rheumatism for years and who never was able to get out of the subnormal class of workers. A careful checking up showed pyorrhea of the

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teeth to be responsible. With six month's supervision and care, that man increased his earning capacity by nearly 100 per cent.

While speaking of mouth conditions, let me recall the case of a man who for three weeks suffered excruciating neuralgia of the face and head. He was the type of man that puts off going to a physician until the last moment. Examination showed that he had a very dirty mouth, a number of snags and some pyorrhea. X-rays showed an unerupted cuspid tooth lying horizontally, the pressure therefrom causing the pain. Twenty-four hours after the removal of this tooth, and the old snags, all pain disappeared. If the plant dentist had been an average dentist no X-ray would have been called for and the man would, for weeks, have lost sleep and time from work, and have considerably reduced his vitality and working capacity.

In passing, we might mention one other case where the man was losing a day or two each week as a result of nausea, sleepy, draggy feeling, practically no ambition for work, and gradual loss of weight. Physical examination showed nothing unusual, except that the teeth were bad. Cleaning up the mouth and pulling out the old snags was followed by immediate improvement. The stomach trouble disappeared. In six weeks he gained seven pounds and had a new bite for work.

DIAGNOSIS NECESSARY

The plant dispensary, with the economic pressure back of it to get results, will go farther to establish a diagnosis than the family physician. It sees the financial advantage to the patient and to the company, to spend a few dollars for consultation or for X-ray. If the employee cannot pay for the consultation, the plant physician can always place his hands upon some consultant on the outside who will do the work for nothing. There is a drive behind the plant physician to get a quick result.

Too much cannot be said for physical examinations of employees. No one knows how many cases of incipient tuberculosis are present in his shop force. There are any number of men whose appetites are variable, who tire easily, but who have no cough or symptoms that would make them consult a physician; are perhaps merely irritable, and have a draggy feeling and no "pep." They attribute their weariness to the job. In so many cases of an early diagnosis of incipient tuberculosis, an enforced rest of a month or two will put these men on their feet again.

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INDUSTRIAL CROSSED EYES

The development of the human potential with all of its mutual and economic advantages will not be introduced in industry where the employer does not possess some social vision. I am thinking just now of one narrow-visioned employer who was recently interviewed by some one who was anxious to gain a consensus of opinion as to the value of employees' service departments. The total human equation in this particular industry, employing some 1100 men, was represented by a mutual aid to which the company contributed annually the large sum of $100 (less than nine cents per man)! It was necessary for that association at their annual picnics, given for the purpose of raising money, to invite employees of a number of other smaller concerns. In other words, for the sake of a few dollars raised by inviting outsiders, this company blindly encouraged the undermining of any good feelings of fellowship that might have been encouraged among its employees by this one annual getting-together. The same employer boasted that the efficiency plan of wages greatly reduced the cost of production, returning ten dollars for each dollar put into that system.

In discussing his men he spoke only of their lack of loyalty and the lack of loyalty on the part of the foremen. With an injured air he told that petitions for the unionizing of the employees had been in circulation in his shop for two weeks with the full knowledge of the foreman before he discovered that fact. The result is, he says, that the shop is fully organized and the union has his company under its thumb. It seems that it had been the custom of this company to entertain the foremen once a month with a dinner and smoker, and that one of these entertainments was held the night before the discovery of the petitions. With stupid satisfaction he said that thereafter foremen's meetings ceased. It is not surprising to note in passing that the labor turnover in this plant is 305 per month. This man who gives the whole sum of $100 toward the sole coöperative effort on the part of the men to care for themselves in times of illness loses $100,000 per year in excessive labor turnover.

If I were called upon to make a diagnosis of that employer, I would venture to say that he had an aggravated case of mental strabismus or was mentally cross-eyed. He does not realize that the sound-minded industrial procession is passing him. He does not know that the movement for the conservation of the industrial worker marks the greatest change in the attitude of society of the twentieth

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century, that next to the municipality the industrial corporation is the largest social unit, that as such it partakes of many of the characteristics and functions of a governmental subdivision. He does not realize that his industry is an example of one selfishly administered, and as such is a menace to the peace, prosperity and happiness not only of the members of his industrial unit, but a menace to the rest of the community members. A coldly calculating, selfish enterprise, no matter how big, engenders selfishness, distrust, envy and hate in individuals in and about it. As a by-product it manufactures class feeling, which other social agencies vainly try to counteract. Conversely, a socially organized, profitable, and far-sighted business enterprise, by its very existence, continuously creating more work for more people, is not only a great financial asset to the community, but is of definite social value as well. The first grows at the expense of society which gave it life. The second is one of the taproots of society. The first produces the malcontents, the industrial hobo, the I. W. W. The second creates intelligent, contented citizenship, the only hope of a democracy.

THE PHYSICIAN IN INDUSTRY

To men who are attempting to fit their enterprises to this latter classification, to men who are seriously at work solving the problem of the human potential in industry, permit me to say that most of them are overlooking the possibilities for service that the socially minded physician may render employers and employees. The proper place has not yet been accorded him. He has not been given an opportunity to make one for himself. It doesn't count for much if surgeons are employed in a plant to care for the injured. The surgeon is in just the same relation to a business and the employees as is the electrical repair man who replaces the fuse and looks after short-circuits. What is needed is a doctor, a combination general repair and safety engineer, to look after the human machinery, to study stresses and strains on it, to give warning of a probable breakdown, to advise easing up on the load until the human mechanism has been readjusted, to do the hundred and one things that make for comfort of mind and body.

COST OF ILLNESS TO CAPITAL AND LABOR

When we are told by investigators that only one industrial worker in five in need of a physician calls one, we may know what

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this shortsightedness in them is costing in lost time. We may also know what great service the industrial dispensary may render.

The loss of wages to the worker on account of preventable illness runs annually to the billion-dollar mark. To the employers the loss must surely be twice that amount when we remember what a large part bad health plays in inefficiency, in irregularity of attendance, with its consequent poverty and low standard of living, in its frequent shifting from job to job, in its undermining of character and stability, in inducing alcoholism and other vices. The man struggling against a physical defect uses up every ounce of energy and loyalty to support his family. Can he have any loyalty left? Is it human to expect it?

Are we going to meet this great medical and economic question by the general introduction of the physician in industry or are we going to sit idly by and permit the propagandists to persuade our legislators that compulsory sickness insurance alone will assure every worker adequate medical service. I personally disbelieve that compulsory sickness insurance will produce that result, but this legislation is inevitable, unless industry grasps its opportunity and shows society that it is willing to undertake a method of health insurance through its own dispensaries, whose costs will be negligible compared to compulsory sickness insurance and whose results for national health will be infinitely greater. If business is not big enough to see the social and economic advantage of some system of self-imposed compulsory medical supervision of employees, then some of the most staunch opponents of compulsory sickness insurance will have to become its active proponents.

The industrial dispensary will lessen disease, increase the number of working days as well as working capacity and thereby increase the purchasing power for adequate medical service for the families of the workers. Medical care in industry is not a charity. It pays the best dividends of any department in business. It secures a new arm to the health department and makes possible preventive medicine on a scale yet undreamed of. Witness the reduction of 75 per cent of the lost time on account of illness in the employees of the Norton Company who use the medical department. In attacking directly such problems as personal hygiene, bad housing and living conditions, alcoholism and venereal disease, it will make a real contribution to national health and social welfare. It will immediately help cure the legislative mania with which the American people are cursed.

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Thus in a feeble way have I attempted to give you a glimpse of the contribution which the physician in industry may make toward increasing the human potential in industry. If it has served to awaken your interest and later investigation, it will not have been in vain. The problem is yours. We should all be at work on its ultimate solution. Of this I am certain — the industrial health department can be made the great human laboratory that will help to refine out the dross and hasten the day of industrial betterment, the ultimate day of a better understanding.

DISCUSSION

R. G. WILLIAMS emphasized Dr. Geier's statements, citing The Norton Grinding Company, which for a number of years had been practicing a good many of the things Dr. Geier advocated. This company had an industrial health department, and it was just as indispensable as the telephone. They could prove to anyone interested that it was a dollars-and-cents proposition. As an example, soon after the department was installed and the men were just getting confidence in the work, an epidemic of grip broke out in the town. About half of the men who developed symptoms immediately got in touch with the plant physician; the other half did not, but held off as long as they could, and eventually lost considerable time. The men that used the hospital lost on an average 19.2 less hours per man per month than the men who did not.

FRANK B. GILBRETH. I want to emphasize one statement in this remarkable paper, not with the idea that it is the most important, but that that one thought would warrant the paper even without the rest of its contents. I refer to the conservation of industrial workers.

We are very much interested in the work of conservation of industrial workers who have been crippled both in the war and in the industries. It will probably surprise you to know that in Canada the number of cripples who return from the war is not as great as the number of industrial cripples for the same length of time in Canada. Statistics showing this may be obtained from those in charge of the reëducation of the soldiers in Canada. Statistics from our own country are published in a remarkable book to be obtained from the Commissioner of Vital Statistics of the State of California.

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In the work that we have been doing with the coöperation of people in foreign countries we have found a tremendous number of jobs for crippled soldiers as a result of which they can practically date the beginning of their financial prosperity from the time that they were injured. The work undertaken in finding occupation for these industrial cripples has been successful to an extent that has been perfectly astounding, and the same thing will apply to placement of reëducated industrial workers, if they are given proper attention.

The great need is for adequate teaching, and this need can best be met now, when the subject of the cripple holds worldwide interest. Immediately after the war began I went to Washington to try to get a bureau started somewhere that would take up the question of providing teachers for crippled soldiers, with the idea of training them so that we could properly handle the cripples that will come back to us. It takes two years to teach anyone to handle the best methods of teaching cripples and it is absolutely necessary to make preparations *now*.

Mistakes have been made in other countries in the matter of teaching crippled soldiers, where they have often been taught to make baskets, because the vocation of basket making might have been the only one that the teacher could teach.

The cripple must be taught *not* primarily what the untrained teacher wants to teach, but *what he needs to learn*. He must be provided with an occupation that develops him mentally and physically, and that satisfies his desire to do "a man's job."

It is the duty of this Society to see that the training for efficient teachers is provided not only in the schools and colleges, but also in the industries. The teachers must know how to prepare the cripples to go back into our shops and offices — must be able to furnish practical as well as theoretical knowledge.

Then, when the need for reëducating war cripples is over, they can turn their energies to the cripples of the industries, to whom Dr. Geier has so eloquently called our attention.

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No. 1600

REPORT OF COMMITTEE ON RECOMMENDED PRACTICE FOR STANDARDIZATION OF FILTERS

To the Council of The American Society of Mechanical Engineers:

Your committee, appointed to make recommendations as to how to *rate the capacity of mechanical filters*, desires to submit the following report:

MUNICIPAL VS. INDUSTRIAL FIELD

2 The field of mechanical filtration may be arbitrarily yet definitely divided into two parts: One, the purification of drinking water or water for domestic supply, and the other the purification of water for other purposes, such as industrial uses.

MUNICIPAL PRACTICE SUBSTANTIALLY UNIFORM

3 On account of its importance and the large expenditure involved, especially in connection with municipal plants, much time and study have been given to all features of the filtration of water for domestic use. A large amount of data gathered through laboratory tests, and experience covering long periods in the practical operation of municipal plants, have brought into quite uniform adoption by all engineers engaged in such work the use of a rate of filtration of 2 gal. per min. per sq. ft. of filtering area for domestic supply.

DEPARTURES FROM NORMAL MUNICIPAL RATE PERMISSIBLE

4 While stating as a matter of information that such a rate is applicable in the great majority of such cases, your committee does not feel warranted in setting forth this rate as one to be adopted for

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all cases. As a matter of fact, the installation of a municipal filtration plant usually is done, and always should be done, under the advice and supervision of a competent filtration engineer engaged for the purpose, and the rate of filtration as well as other points of construction and operation should be left to his judgment, based upon the local conditions that may exist. For this reason, your committee feels that it is advisable and in accordance with the spirit and intent of your instructions to refer herein chiefly to the filtration of water for other than municipal purposes.

VARIOUS VIEWS CANVASSED

5 Your committee in considering this subject has sought information and assistance from many sources, and we desire herewith to express our appreciation of the many courtesies extended to us by those thus called upon for data or comment.

GRAVITY VS. PRESSURE FILTERS

6 It may be well here, in view of the misunderstanding that seems to exist to some extent, to make some reference to the two different types of mechanical filters known as the gravity type and the pressure type. With both types, purification is accomplished by passing the water through a filtering bed, which in practically all cases is sand, and the purification is dependent upon the property or power of the bed of sand to remove suspended impurities from the water passing through. This property is one inherent in the filter bed itself and while it will be affected by the rate at which the water passes, it is not altered by the incidental fact of the water being or not being under more than atmospheric pressure. While, with additional pressure available, more water can be forced through a pressure filter than a gravity filter of given size, there is no difference in the principles or methods employed that warrants a higher rate of filtration with such filters than is acceptable for open or gravity filters when similar results are to be obtained.

EXPERIENCE LEADING TO STANDARDIZATION

7 From the information gathered it was made apparent that experience has already brought about a substantial unanimity of opinion and practice on the part of all those who, as engineers, chemists or manufacturers, are brought into close contact with the field of mechanical filtration as to the limits within which permissible rates of filtration must fall. A very definite rate has become estab-

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lished in connection with municipal work, and indeed if there had been anything like the publicity in connection with filtration of water for other purposes that has obtained in connection with gravity filters such as are installed for municipal work, it is probable that there would have been no occasion for such investigation and report as this committee has been called upon to make.

TENDENCY TO OVERRATING

8 While our investigation has made the above situation apparent, it has also developed the fact that there have been many filters installed in which the rate of filtration per unit of area is beyond, and sometimes far beyond, that at which good results can be expected or required. In some cases this has been due to the specifications under which the filters were installed, and in others, to what must be called an overrating of the capacity of filters on the part of manufacturers. It is easily possible to force or pass through a filter of given dimensions much more water than it will properly filter, and in view of this it must be expected that there will be more or less yielding on the part of manufacturers placed under competitive conditions to the temptation to overrate their filters.

NEED FOR DEFINITE, REASONABLE SPECIFICATIONS ON CAPACITY

9 This condition emphasizes the need and value of a pronouncement on this subject by some such body as The American Society of Mechanical Engineers which will serve for the information and guidance of those who, while having occasional need to specify or use mechanical filters, do not have opportunity to keep fully informed of conditions in that field. It is, therefore, hoped that this report and its recommendations will be of real value to engineers by placing before them information as to what is now the best opinion and practice, and thus enabling them to protect their own work and their clients' interests. To this end your committee most heartily and urgently recommends that when specifying filters there be included not merely the amount of water to be filtered per unit of time, but also specifications as to the rate of filtration per unit of area, or else the area or dimensions of the filter bed. Specifications thus written will insure fair competition and more satisfactory results.

IDENTITY IN GENERAL DESIGN

10 The same general design and the same principle of operation are followed by all the leading manufacturers of mechanical filters,

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the filtration being downward through a bed of sand superimposed upon layers of gravel, the filters being washed by a reverse flow of water. Competition in construction is, therefore, limited to the excellence of materials and workmanship, to the perfecting of details and to adaptations for convenience in accordance with good filtration-engineering practice. While this affords abundant opportunity for conscientious care and requires familiarity with the history of filtration and thorough knowledge and observance of the results of experiments and tests, it does not allow any application of ingenuity to change fundamental requirements that are dependent upon natural laws.

UNNECESSARY TO STANDARDIZE CONSTRUCTION DETAILS

11 Your committee feels that it would be unwise, at least at this time, to attempt to standardize details of construction, there being a wide range in this field for individual preference or convenience, but there may well be established a standard in regard to the rate of filtration, since the object thereby sought is not mere uniformity but compliance with the limitations imposed by the laws of nature, so that the possible benefits of filtration will be actually and fully realized. It would thus seem to be self-evident, even if it were not fully established by experiment and experience, that the capacity of any filter is dependent upon and determined by two factors:

a The permissible rate per unit of area at which the water can be passed to insure the desired results

b The effective area of the filter bed.

AGREEMENT AMONG LEADING FILTER MANUFACTURERS

12 It was made evident by the data gathered that there is a unity of opinion on the part of those best qualified to judge at what rate water may be passed per square foot of filter area to secure desired purification, and that there is a close agreement in the practice of all the leading filter manufacturers in rating the capacity of a filter.

FORM OF EXPRESSING CAPACITY

13 For convenience, we have expressed the rate of filtration in terms of gallons per square foot of superficial filter-bed area per minute, thus combining units of quantity, area and time in a way to make easy the calculation of the amount of water any given filtering unit will properly handle or to estimate the area of filter-bed surface

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that will be required for a given supply. The filtering area should be computed on the upper surface of the filter bed, as the latter lies during normal filtering operation, and no attention should be paid to a greater cross-sectional area such as is sometimes found in horizontal cylindrical filters.

CARE AS TO MAXIMUM DEMAND

14 In deciding upon the size of filters to be installed in any instance very careful consideration should be given to the maximum flow that will be required at any time, and ample capacity provided. Where the demand is irregular, the maximum requirement is much greater than the average or minimum consumption, and either adequate storage for filtered water should be provided or the rated capacity of the filter made equal to the maximum demand. All filters are capable of passing more than their rated capacity, but beyond certain fairly narrow limits this is always at the expense of the quality of the filtered water, unless more than ordinary care is taken in efficiently coagulating the unfiltered water. As already intimated, the persistent use of moderately high rates above the normal and the occasional use of excessively high rates should be discouraged, if not prohibited.

DEPTH OF FILTER BED

15 While in a sense consideration of the filter bed may not be included within the instructions given your committee, we feel that some remarks in this connection will be of value, especially as there seems to be an opinion in some quarters that the use of a thicker filter bed or special methods or appliances for washing, or similar features, make higher rates of filtration permissible. In regard to such points, we would say, that while of course there is a minimum thickness of filter bed that must always be maintained for safety, better results do not follow increased depth. In fact, an excessive depth of sand bed is in some instances objectionable, as it may interfere with proper washing. We find that the minimum thickness of filter bed should be 27 in., of which at least 18 in. should be sand or similar fine material. A filter bed thickness of 33 in., of which at least 24 in. is sand or similar fine material of suitable size and grade, is recommended.

INFLUENCE OF FILTER WASHING

16 While efficient washing of the filter bed must be provided for and while the use of special means or appliances, such as stirrers, air

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agitation or other means of breaking up the filter bed, may be of value in some cases as means of securing economy in time or of water consumed in washing the filter bed, the direct effect of such means is limited to that secured during the washing process and such effect has no influence one way or the other on the permissible rate of filtration, which is dependent upon and limited by properties inherent in the filter bed itself.

NORMAL FILTERING MATERIAL

17 The most desirable filter medium is a granular substance of a hard, non-porous, insoluble character, with grains substantially uniform in size and shape, the exact size and uniformity of the particles being open to some variation depending upon local conditions. If properly washed, such a filter bed will remain in efficient working condition for several years.

SPECIAL FILTERING MATERIAL

18 Bone charcoal or other porous material is sometimes of aid in the removal of iron, color, tastes or odors. But if they are used it must be recognized that growths of bacteria in the effluent are very likely to occur, although there is no evidence to indicate that such growths include disease-producing germs. These porous media may be used in single or double filtration, as noted in Pars. 20 to 23, inclusive.

RECOMMENDED RATE OF FILTRATION

19 The permissible rate of filtration in any instance depends upon the character of the water to be filtered and the purpose for which the water is used. If the water is for domestic purposes, whether the filters are installed in a municipal plant or otherwise, the rate of filtration should not exceed that which has been adopted for such service by universal consent of filtration engineers. We therefore recommend that:

a Whenever the water is to be used for domestic purposes or to secure full bacterial purification, the capacity shall be based upon a rate of filtration not to exceed 2 gal. per min. per sq. ft. of filtering area and a coagulant must be used.

b Where a lesser degree of purification is required, either because the water is not to be used for domestic consumption or because the water to be filtered is already sufficiently free from bacteria, or where the filtered water is

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to be effectively sterilized, a higher rate of filtration may be used, but not to exceed 3 gal. per sq. ft. per min.

DOUBLE FILTRATION IN SPECIAL CASES

20 Your committee finds that there is a limited use made of double filtration; that is, the water is passed through two filters placed in tandem. The consensus of opinion of those consulted and the recommendation of your committee is that when both filters are filled with the same medium this is not the best practice, but that better results will be obtained from the same filters operated in parallel, if they are properly constructed, owing to the slower rate of filtration.

21 Double or tandem filtration may, however, be used to advantage under some special circumstances, as, for instance, where the filter medium in the second filter is of a very close texture, so as to secure the very highest quality of filtered water by removing fine suspended matters that may pass through an ordinary filter bed.

22 Double filtration may also be of advantage where the use of a coagulant is not desired or where it is intended to remove iron, color, odor or taste. In such cases sand can be used in the first filter and bone charcoal or similar porous medium in the second. Such practice, however, should be limited to cases where an increase in the numbers of harmless water bacteria, such as frequently occurs in the effluent of a porous filter medium, is not objectionable.

23 If double filtration is employed, the rate of filtration should not exceed the rate for single filtration, unless warranted by the results of experiments or upon the advice of a competent filtration engineer.

STERILIZATION

24 In earlier years it was frequently the custom to sterilize filter beds with steam, but it was found that the benefit of this treatment was temporary, and it frequently resulted in the growth of water bacteria within the filter. At present, sterilization is normally and preferably secured in the filtered water through the aid of liquid chlorine, hypochlorite of lime, or ultra-violet rays. When properly applied, such treatment will destroy all objectionable bacteria.

PREPARATORY TREATMENT

25 While this report deals essentially with filters themselves, it is proper to point out that mechanical filters, with the rapid rate of

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filtration employed, cannot be expected to accomplish the best obtainable results without the securing of proper coagulation; and if the raw water is very turbid, then preliminary sedimentation also must be considered.

26 In closing this report the committee desires to express its deep loss in the death on August 7, 1915, of J. C. W. Greth, Mem. Am.Soc.M.E., one of the original members, and also its appreciation of his aid in collecting data on the practical state of the art and of his judicially expressed opinion as to the basis of this report.

Respectfully submitted,

GEORGE W. FULLER, *Chairman*,
JAMES C. BOYD
ARTHUR M. CRANE
PHILIP N. ENGEL
MARTIN F. NEWMAN
WILLIAM SCHWANHAUSSER

COMMITTEE ON FILTER STANDARDIZATION

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No. 1601

MEETINGS SEPTEMBER–DECEMBER

MEETINGS OF SECTIONS

NEW ORLEANS, SEPTEMBER 7

Illustrated Lecture: Notes on Shipbuilding, F. J. French.

PROVIDENCE, SEPTEMBER 18

Illustrated talk by Prof. J. Ansel Brooks on his trip to Honolulu.

ST. LOUIS, SEPTEMBER 21

Address by Judge Thomas L. Anderson on Patriotism, with informal talks by R. L. Radcliffe, John Hunter, L. Gustafson, H. R. Setz and G. R. Wadleigh.

HARTFORD, SEPTEMBER 28

Hartford Branch organized. Officers elected: B. M. W. Hanson, Chairman, Hiram P. Maxim, Vice-Chairman, S. F. Jeter, Secretary-Treasurer; M. D. Church, Chairman Membership and Aquaintanceship Committee, and C. L. Grohmann, W. H. Honiss, C. D. Rice, A. D. Risteen, and C. H. Veeder, members of the Executive Committee. Addresses by President Hollis, Past-President Jacobus, Secretary Rice, Ernest Hartford, F. R. Low, P. B. Morgan and H. B. Sargent.

MILWAUKEE, OCTOBER 3

Illustrated Lecture: Manufacture of a 9.2-in. High-Explosive Howitzer Shell, Chester A. Lucas.

BUFFALO, OCTOBER 10

Paper: The Internal-Combustion Engine and the War, George W. Dunham.

PROVIDENCE, OCTOBER 10

Subject: The Gasoline Engine, with Particular Reference to Aeronautics, Prof. Dean A. Fales.

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BOSTON, OCTOBER 11

Lieutenant Morize spoke on The Differences in Modern Warfare Methods and Those in Vogue in the Past. Major Cole, Commandant at M. I. T., gave a talk along the same lines.

NEW YORK, OCTOBER 16

Address: The Evolution of Manhattan from an Indian Village to a Great Metropolis, Dr. T. Kennard Thomson.

PHILADELPHIA, OCTOBER 16

Joint meeting with the Engineers' Club of Philadelphia. Address: The War's Effect on Merchant Shipbuilding, Homer L. Ferguson.

PROVIDENCE, OCTOBER 16

Illustrated Lecture: The Army Cantonment at Ayer, Mass., F. A. Barbour.

ST. LOUIS, OCTOBER 16

Dinner and reception at the Missouri Athletic Club, with President Hollis as the guest of honor.

SAN FRANCISCO, OCTOBER 16

Illustrated Lecture: The Tunnels of San Francisco, M. M. O'Shaughnessy.

BUFFALO, OCTOBER 17

Illustrated talk on Scientific Research by Dr. C. E. K. Mees.

CINCINNATI, OCTOBER 18

Address: The Research Laboratory Applied to Industry, F. O. Clements.

ST. LOUIS, OCTOBER 22

Joint meeting with the National Committee on Sections. Illustrated Lecture: The Development and Operation of a Large Power Station, John Hunter.

LOS ANGELES, OCTOBER 23

Meeting with the Joint Technical Societies, President Hollis and Dr. George E. Hale giving addresses.

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BUFFALO, OCTOBER 24

Paper: Problems in Crankshaft Design, Otto M. Burkhardt. Published in THE JOURNAL, March 1918.

DETROIT, OCTOBER 25

Dinner and smoker held, with the National Committee on Sections as guests. Discussion on Problems of Shop Management by Prof. Walter Rautenstrauch and D. Robert Yarnall.

SAN FRANCISCO, OCTOBER 25

Joint meeting with the local branches of the national engineering societies, with addresses by President Hollis, Prof. Harris J. Ryan, Prof. C. D. Marks, Prof. A. C. Lawson and Dr. L. H. Duschak, on the general subject of The Relation of Engineering to the War.

BUFFALO, OCTOBER 31

Paper: Industrial Production, William M. Dollar.

ATLANTA, NOVEMBER 6

Address: Aviation with Relation to the War, Prof. J. S. Coon.

BALTIMORE, NOVEMBER 7

Papers: Evaporators, William L. De Baufre; Considerations in Municipal Ownership, Prof. A. G. Christie.

INDIANAPOLIS, NOVEMBER 7

Illustrated Lecture: Canada at War, L. O. Armstrong, followed by Captain Brown, of the Canadian Engineers, who told of his experiences in the trenches, and Captain Reeves, U. S. A., who spoke on the qualifications required by men for the Aviation Service.

PROVIDENCE, NOVEMBER 9

Paper: Handling and Moving of Material, Chester T. Morey.

ST. LOUIS, NOVEMBER 9

Joint meeting with the Associated Engineering Societies of St. Louis in a farewell dinner to John Hunter, who had been called into Government service.

ERIE, NOVEMBER 13

Joint meeting with the Engineers' Society of Western Pennsylvania. Illustrated Lecture: Pulverized Coal and Its Future, H. G. Barnhurst.

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NEW YORK, NOVEMBER 13

Paper: Concrete Piling, Maxwell W. Upson.

PROVIDENCE, NOVEMBER 13

Paper: Some Steels Used in Machine Construction, Chester B. Sadler.

CONNECTICUT, NOVEMBER 14

Initial meeting at New Haven with two sessions. Afternoon session: Paper on The Problem of Coal Conservation by Prof. L. P. Breckenridge, with discussions by Professors Seward, Perry and Barker and Messrs. R. J. S. Pigott, A. J. German and T. W. Russell, Fuel Administrator for Connecticut.

Evening Session: Paper: Fuel Conservation by the Bureau of Mines, O. P. Hood. Discussion by Profs. E. H. Lockwood and L. P. Breckenridge, and Messrs. C. H. Bromley and F. O. Wells. Address by President Hollis.

MILWAUKEE, NOVEMBER 14

Illustrated Lecture: The Design and Application of Magnetic Clutches, B. E. Fernow.

BUFFALO, NOVEMBER 16

Illustrated Lecture: The Modern Cylindrical Grinding Machine, Dr. C. H. Norton.

CHICAGO, NOVEMBER 16

Address: Cantonment Construction, Major Peter Junkersfeld. President Hollis spoke on the Engineer's Task in the Present War.

PROVIDENCE, NOVEMBER 20

Illustrated talk on the Machining of a 9.2-in. High-Explosive Shell, by Chester L. Lucas.

BUFFALO, NOVEMBER 21

Subject: Electricity on the Barge Canal, L. H. Hart.

WORCESTER, NOVEMBER 22

Subject: Fuel Conservation. Discussion by President Hollis and Prof. L. P. Breckenridge.

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BOSTON, NOVEMBER 23

Address: Recent Development of the American Marine Industry, H. G. Smith, followed by a talk on the Rapid Building of the Squantum Plant for the Construction of Submarine Destroyers, by E. H. Ewertz. Address by President Hollis.

ST. LOUIS, NOVEMBER 23

Address: American, English and French Relations, Past and Present, Prof. C. S. Boucher.

LOS ANGELES, NOVEMBER 24

Automobile trip to the Mount Wilson Solar Observatory, where the new 100-in. telescope nearing completion was inspected.

PHILADELPHIA, NOVEMBER 27

Paper: Manufacturing in Relation to Banking, Research and Management, Prof. Walter Rautenstrauch.

PROVIDENCE, DECEMBER 5

Subject: Foundation Work in Providence.

BUFFALO, DECEMBER 6

Illustrated Lecture: Aeroplanes, Uncle Sam's Infant Industry, G. Douglass Wardrop.

MINNESOTA, DECEMBER 7

Joint meeting with the A.I.E.E. and several other technical societies. Lecture: Wartime Work of the United States Signal Corps in Aviation and Electrical Communication, L. D. Wildman.

PHILADELPHIA, DECEMBER 11

Paper: Offensive Against the Submarine, Joseph A. Steinmetz. Published in THE JOURNAL, March 1918.

PROVIDENCE, DECEMBER 10, 11 AND 12

Papers: Fire Hazards of Celluloid, Frederick J. Hoxie; Engineering of Silent-Chain Drives, J. S. White; Boiler Efficiencies, George F. Wheaton.

BUFFALO, DECEMBER 12

Address: Industrial Housing, W. Fostergen.

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ERIE, DECEMBER 14

Joint meeting with the Engineers' Society of Western Pennsylvania. Address: Industrial Management, Prof. Dexter S. Kimball.

BALTIMORE, DECEMBER 19

Paper: Microstructure and the Physical Properties of Metals, Dr. D. J. McAdams, Jr., followed by a paper on the Mechanical Problems of the Fertilizer Industry, by Samuel P. Whiteside.

BUFFALO, DECEMBER 19

Paper: The Evolution of the Scale, H. O. Hem.

ST. LOUIS, DECEMBER 19

Joint meeting with the Associated Engineering Societies of St. Louis. Paper: Power-Plant Installation by By-Product Coke-Oven Plants, George B. Evans.

BIRMINGHAM, DECEMBER 20

Fuel Conservation discussed by F. G. Cutler and J. W. Moore. Talk on the Handling of the Sick and Wounded in Actual Warfare, by H. B. Hess, of the United States Medical Corps. Lecture on the Use of Graphite as a Boiler-Scale Preventive, by Samuel Stewart.

CONNECTICUT, MERIDEN BRANCH, DECEMBER 21

Short papers on the Need for Accurate Data in Engineering Organizations by J. L. Hutchinson and Charles N. Flagg.

PROVIDENCE, DECEMBER 21

Paper: From the Coal Pile to the Lamp, Jesse E. Gray.

THE ANNUAL MEETING

Some of the general meetings of the Society have excelled in the number of members and guests in attendance, some in the notable speakers and papers, some in the activity of the discussions, some in the timeliness of the topics on the program, some in the distinguished receptions held by the Society and some in the signal advances in

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the Society's policies; but the thirty-eighth Annual Meeting, held in the Engineering Societies Building from December 4 to 7, 1917, will go down in the annals of the Society as having excelled in all of these, as well as having been an occasion especially distinguished by the patriotic nature of its proceedings.

At the opening session on Tuesday evening the Hon. William H. Taft, ex-President of the United States, addressed the Society on The Nation's Call to The Professional Man. Honorary Membership was conferred at this time on Major-General George W. Goethals.

On Wednesday began the professional sessions of the meeting, starting with an all-day war session at which a series of remarkable addresses on the great engineering problems of the war was given. President Hollis opened this session with his address on Universal Public Service in Peace and War.

Several of the sessions throughout the convention were inspired by the conditions brought about by the nation's entrance into the war. The first meeting of the Gage Committee, on Tuesday afternoon, was of this character, having as it did many delegates in attendance representing departments of the Government, gage manufacturers, manufacturers of munitions in this country and Canada, the Canadian Munitions Board, etc. This phase of the Society's work had its inception at the Spring Meeting of 1917, when a resolution was adopted calling upon the Council to appoint a Committee to coöperate with the Government in laying a foundation for the enormous munitions-manufacturing program. In order to secure concerted action, the Society gave an informal dinner to a number of Government officials and members of the Council of National Defense, following which there was a discussion of the subject of gage certification and standardization.

Later, coöperation was secured with the Society of Automotive Engineers, and it was generally agreed that the most effective arrangement would be for standards of measurement, master gages, reference gages, inspection gages, etc., to be certified under the direction of the Bureau of Standards. At the public hearing there was a general discussion of this subject and resolutions were passed asking that gages used upon Government contracts should be certified by the Bureau of Standards.

One session under the direction of the Sub-Committee on Machine Shop Practice was devoted to the question of inspection, with particular reference to the manufacture of munitions. Another session dealt with new problems of management incident to the war.

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At the Business Meeting, President Hollis delivered an address which dealt with the activities of the Society for 1917 and was in the nature of a report. Following it was the presentation by Mr. W. M. McFarland of a bust of Rear-Admiral Isherwood to the Society.

Besides these distinctly war sessions there were technical sessions of the usual high order of merit dealing with power-plant, textile, industrial safety and general topics.

On Friday was held the public hearing of the Power Test Committee, attended by official representatives from various engineering societies, college laboratories, governmental departments, railroads and manufacturing firms.

The entertainment features of the convention began with a reception by the Society to the President and President-elect on Tuesday evening after the opening session. A "get-together" meeting for the members followed by a smoker was held on Wednesday night, when Past-President John R. Freeman held the interest of the audience by a diverting and enlightening account of his trip to the Orient the preceding winter. On Thursday evening Dr. John A. Brashear gave his remarkably fine lecture on the Science of the Beautiful in Commonplace Things. There was also a ladies' reception and tea on Wednesday afternoon. Four trips were also arranged for by the Excursion Committee.

On Friday evening the alumni of the following colleges held reunions and many enjoyed what has come to be an annual event: Cornell University, Massachusetts Institute of Technology, Purdue University, Stevens Institute of Technology, the University of Kentucky, and Worcester Polytechnic Institute.

The total registration was 1965, of which 1115 were members and 850 guests, representative of all parts of the country. The national character of the Society, however, was quite as strongly emphasized by the delegates present from the various Local Sections of the Society, of which 19 had representatives in attendance. Important features of the meeting were a Sections session, a Sections luncheon and a Sections conference.

The convention was in charge of the Committee on Meetings, Robert H. Fernald, Chairman; and the entertainment in charge of the New York Section Committee, J. H. Norris, Chairman. The President's reception was under the direction of the House Committee, Frederick A. Scheffler, Chairman. Mrs. William H. Boehm was Chairman of the Ladies' Reception Committee.

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PROGRAM

Tuesday Afternoon, December 4

Public Hearing on Gages.

Tuesday Evening, December 4

OPENING SESSION

Address by the Hon. William H. Taft on THE NATION'S CALL TO THE PROFESSIONAL MAN. Conferring of Honorary Membership upon Major-General George W. Goethals. Report of tellers of election of officers and introduction of the President-elect.

Reception by the Society to the President, President-elect, ladies, members and guests.

Wednesday Morning, December 5

THE SERVICE OF THE ENGINEER TO THE PUBLIC IN TIMES OF CRISES (KEYNOTE SESSION)

UNIVERSAL PUBLIC SERVICE IN PEACE AND WAR, Dr. Ira N. Hollis.
THE ENGINEERING SOCIETIES IN THE NATIONAL DEFENSE, Gano Dunn.
SPECIAL EDUCATION IN TIME OF WAR, Dr. Charles S. Howe.
ENGINEERING RESEARCH, C. E. Skinner.
THE AGRICULTURAL PROBLEM, L. H. Bailey.
THE FUEL PROBLEM, Prof. L. P. Breckenridge.

Wednesday Afternoon, December 5

CONTINUATION OF KEYNOTE SESSION

MOTOR TRANSPORTATION, William P. Kennedy.
ARMY TRANSPORTATION, Major L. B. Moody.
THE AIRCRAFT PROBLEM, Prof. W. F. Durand.
THE SOLUTION OF THE CANTONMENT CONSTRUCTION PROBLEM, Leonard Metcalf.

POWER-PLANT SESSION

PREVENTABLE WASTE OF COAL IN THE UNITED STATES, David Moffat Myers.
A COMMERCIAL ANALYSIS OF THE SMALL-TURBINE SITUATION, W. J. A. London.
BAGASSE AS A SOURCE OF FUEL, E. C. Freeland.
THE COOLING OF WATER FOR POWER-PLANT PURPOSES, C. C. Thomas.
THE STEAM MOTOR IN THE AUTOMOTIVE FIELD, E. T. Adams.

GENERAL SESSION

THE TRANSFER OF HEAT BETWEEN A FLOWING GAS AND A CONTAINING FLUE, Lawford H. Fry.

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A Study of Surface Resistance with Glass as the Transmission Medium, H. R. Hammond and C. W. Holmberg. (Awarded Student Prize, 1917.)

Apparatus for Cooling, Drying and Purifying Air, W. J. Baldwin.

Recent Developments in Balancing Apparatus, N. W. Akimoff.

Plotting Blower-Test Curves, A. H. Anderson.

Cross-Current Predeterminations from Crank-Effort Diagrams, Louis Illmer.

INDUSTRIAL-SAFETY SESSION

Tentative Draft of a Proposed Code of Safety Standards for Elevators.

Tentative Draft of a Proposed Code of Safety Standards for Woodworking-Machine Guards.

RECEPTION AND TEA

Given by the Ladies' Committee in the rooms of the Society.

Wednesday Evening, December 5

Get-together meeting for members, followed by a smoker.

Thursday Morning, December 6

BUSINESS MEETING

Address by President Ira N. Hollis on the Activities of the Society for 1917; reports of the Standing Committees; amendments to the Constitution and By-Laws; award of Student Prize; reports of Professional Committees.

Presentation to the Society by Mr. W. M. McFarland of a bust of Rear-Admiral B. F. Isherwood.

LOCAL-SECTIONS SESSION

Held under the direction of the Sections Committee for a discussion of the work of the Sections and of Society affairs by representatives of 22 Sections of the Society.

GENERAL SESSION

An Account of the Engineering Work of E. D. Leavitt, F. W. Dean.

An Exact Volume Regulator for Blast-Furnace Engines, L. C. Loewenstein.

Expenses and Costs, H. L. Gantt.

By-Product Coke and Coking Operations, C. J. Ramsburg and F. W. Sperr, Jr.

The Submarine, C. H. Bedell.

Combined Stresses, A. Lewis Jenkins.

The Trumble Refining Process, N. W. Thompson.

LUNCHEON

Address on The Relation of Industrial Management to Engineering, by Prof. Dexter S. Kimball.

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Thursday Afternoon, December 6

MACHINE-SHOP SESSION

Topical Discussion on the subject of Inspection, with the following introductory discussions:

THE LOGIC OF INSPECTION, A. L. De Leeuw.

THE RELATION OF INSPECTION TO PRODUCT, F. A. Waldron.

GENERAL PRINCIPLES OF GOVERNMENT INSPECTION AND RELATIONS BETWEEN INSPECTORS AND MANUFACTURERS, Col. B. W. Dunn.

TEXTILE SESSION

LABOR-TURNOVER RECORDS AND THE LABOR PROBLEM, Richard B. Gregg.

ACCIDENT PREVENTION IN THE TEXTILE INDUSTRY, David S. Beyer.

THE MOISTURE CONTENT OF TEXTILES AND SOME OF ITS EFFECTS, William D. Hartshorne.

Thursday Evening, December 6

LECTURE AND ANNUAL REUNION

THE SCIENCE OF THE BEAUTIFUL IN COMMONPLACE THINGS, Dr. John A. Brashear: Followed by the annual reunion and dance.

Friday Morning, December 7

MANAGEMENT SESSION

Topical Discussion on the Employment of Women in the Skilled Industries, with introductory addresses as follows:

THE WOMAN WORKER, John W. Upp.

INFLUENCE OF ENVIRONMENT ON THE WOMAN WORKER, C. B. Lord.

THE ENGINEER, THE CRIPPLE AND THE NEW EDUCATION, Frank B. Gilbreth and L. M. Gilbreth.

POWER-TEST HEARING

Public Hearing by the Power-Test Committee. (Continued in the afternoon.)

Friday Evening, December 7

College reunions.

Convocation of the four national engineering societies to welcome the American Society of Civil Engineers to the Engineering Societies Building.

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THE SERVICE OF THE ENGINEER TO THE PUBLIC IN TIMES OF CRISES

No. 1602*a*

UNIVERSAL PUBLIC SERVICE IN PEACE AND WAR

By Ira N. Hollis, Worcester, Mass.
President of the Society

OUR profession has long been classed as one concerned only with the application of science. It covers a very wide range, reaching, on the one hand, from invention and construction that affect the whole history of this race, on the other hand, to the little things that add only to convenience and comfort in our daily lives. Transportation, for instance, in opening to every nation the products of all others, and in permitting the ready ebb and flow of travel, has had a profound influence upon industry and upon the world outlook of men. Our thoughts have sprung beyond national barriers. This war is a temporary setback, but we shall come out of it stronger than ever for human brotherhood.

In the changes that are coming the engineer can no longer dwell within his technical shell and he must prepare himself to become a citizen of the world upon whose shoulders great economic and social burdens are placed. He must study history, the science of government, and the problems of labor, that he may grow to the maximum of his possibilities. His training has fitted him for anything, providing he does not stop all the humanities after leaving college. His work will be better done for conscientious performance of civic duties and, if thereby he is drawn away from technicalities, his education will have justified itself. At this time there is nothing more important to him than a clarification of his thoughts on govern-

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers, in lieu of the customary Presidential Address.

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ment and public service. He cannot afford to remain outside the life of the nation, and he must exert himself to do and to know. For that reason it is a happy thought on the part of the Meetings Committee to set apart this day for public questions. The first thing in any discussion is a courageous look into our shortcomings as a nation. We have the faults of youth, not because our form of government is inferior, but because it is superior. We impose only as much government on the individual as is absolutely necessary to hold society together.

The great difference between the Allies and the Central Powers lies in the attitude of the individual toward the state. Two conceptions are found in modern times; one springing out of Rousseau's revolutionary doctrine that government is derived from the consent of the governed, and the other from the ancient divine right, under which the governed derive their privileges from the consent of a ruling class, or of a crowned head.

In the first case society regulates itself and the state is wholly a possession of individual citizens. In the second case society is regulated by those set above, and the individual belongs entirely to the state, in whose service anything may become justified. These two ideas lead to characteristic failure when carried to extremes; as, for instance, in a democracy, liberty unchecked by public opinion is likely to become license, and freedom may mean simply the power to do as the individual pleases, without reference to the common welfare; equality would be nothing but a dead level of property under this theory that would render democracy the most oppressive socialism. In an autocracy, the individual, as the property of the state, may become a murderer, a liar, a thief, and the lowest of conspirators without loss of station, provided his deviltry is committed at the behest of the ruling power. Secret diplomacy against the well-being of other states will always flourish under a military autocracy.

In the first of these cases you have the destruction of individual conscience as related to the state; in the other, the complete breakdown of national morality in relation to the world. We have these two extremes at the present time side by side in Europe: Prussia with the unbridled license of the ruling classes to do evil, that their good may spring from it, and Russia with a complete collapse of state morality in the hands of ignorant socialism.

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TRAINING FOR PUBLIC OFFICE

Extremes in government are always wrong, and wise men have studied for ages how to check that tendency. It is perhaps the most important problem that we have in our own country, where every individual can express his views freely without fear of being arrested for adverse criticism against a dynasty. Every public officer is a public possession, and can be dissected without any hindrance on the part of the law. This implies for success in government a self-control that comes only with training, and the American people may well pause to think more seriously about training for public office and for citizenship in a democracy. We have had very loose views on this subject ever since the formation of the Republic. Anyone may be put into any office on the principle that American common sense will somehow muddle through. Hence this subject is more than timely. It is the psychological moment when all people, especially the engineers, should strike a good blow toward the education of men and women for service under the state, and for that kind of self-control and sacrifice that produces efficiency in a republic.

As a matter of fact, this whole subject is of vastly greater importance at this session of The American Society of Mechanical Engineers than any technical or professional paper could possibly be. While a single invention may often change the whole course of human history, the freedom of man for his own development is so dependent upon his training, or education, that we as engineers ought now to turn our minds entirely away from technicalities of science to the fundamental rules upon which all society must be based. We are citizens first and engineers afterward, and while we know that the externals of civilization have only kept pace with the progress of our profession, we know also that the spiritual side of man's nature is a development of the geologic ages. Short periods of history disclose relatively little change. During nineteen hundred years of great material growth, humanity as a whole has not taken a single step toward the realization of human brotherhood, except, perhaps, in the surrender of legal ownership in slaves. The mechanic who works for us lives in a style that a monarch of the middle ages might have envied. A traveler four thousand years ago coming out from Egypt would have written a book about his adventures in crossing the little arm of the Mediterranean, called in ancient times the Syrian Sea. But we moderns have many in America who consider a journey around the world only an event worthy of an evening's

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conversation with a few friends. Through engineering we know the world and every corner of it as our grandfathers could not have known it. We know how nation has come to be dependent upon nation. Yet ethically we are still as blind as the money changers who were driven from the temple by Jesus Christ, and we are fighting the most horrible war in all history.

THE ENGINEER'S TASK IN WAR

Every war has its roots deep down in the history of the race, and it is often very difficult to trace the causes. In our Spanish War the immediate cause, or the immediate event, that brought about the war was the sinking of the *Maine* in Havana Harbor under circumstances that seemed to put the responsibility on the Spaniards. The real basis of the war dated back for generations, and was only the result of many struggles against the autocratic power of a nation exploiting American colonies for its own benefit, without any reference to the good of those who were exploited. This war too is the result of great forces that seem always to have existed. It is made more horrible by the inventions that began with James Watt's improvement of the steam engine into a workable machine. While it is not caused by the work of the engineer, it is essentially an engineer's war, in the respect that it uses all of his talent toward making the war more terrible. It is the culmination of the century of invention that followed Watt, and represents a struggle between those who have deliberately conspired to make use of all human resources and invention for securing dominion over the world, and those who believe that man advances in true happiness under individual freedom far better than under the direction of autocracy.

It is our task as engineers to assist in making the world safe against the forces that we have unloosened, so that the century may not close with a total failure of the civilization of Christian races. It is we who have developed the applications of science, and it is we who are using it to destroy one another, forced into the struggle by the rulers of a nation that knows no right except might, and no mercy except that which is taught them by the sword. Our great problem will be, not how to develop further, but how to tame what we have. Unless some conscience is aroused that science is not to be used against man, but for him, then it will never be safe for this world. It will always be an explosive ready to go off and destroy. The poisoning of wells is nothing beside the reversal of preventive

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medicine into a destructive agency. Every practical invention can be turned into evil for destroying the white races in favor of the yellow or black men, who have no science.

THE BEST TRAINING AN EDUCATED CONSCIENCE

We as engineers must take our share in quickening the conscience of the American people toward the danger of unlimited, unchecked forces, and in preaching night and day the importance of an educated conscience. That is, after all, the most effective training for public service, and the best antidote against the unholy advance of scientific brutality.

It is a curious thing that James Watt should have been prevented from practising a trade that he had learned in London by the trade guilds of Glasgow. The potent influence over his life and over human history sprang out of his having been driven to take refuge in a university as mathematical instrument maker, where he was called upon to do all kinds of odd jobs in connection with a physical laboratory. By a strange irony he improved the steam engine and thereby let loose the forces of labor saving against the trade unions, thus creating problems infinitely more difficult than anything connected with labor a century and a half ago.

In what respect is democracy to be preferred to an autocracy which safeguards the material welfare of its citizens and provides through state regulation for their comfort? That question is an important one before the American people, and we should study it in order to understand and buttress our own institutions. Our education has taught us that there is only one answer, and we believe that science is safe only in a democracy such as ours.

Efficiency has come to mean something new to us, and by it we can make an adequate comparison between the two forms of government, but we must take efficiency in the most comprehensive sense of the word. It is nothing to mankind if by reducing the labor required to produce the necessities of life, it simply enables a country to support a larger population. The thing worth while is righteousness and satisfaction in our lives, not a larger number of human beings on this planet. One can express but little sympathy with certain exaggerated notions about race suicide. There is no such thing. There is an ebb and flow and a divine law under which some families gradually die out and others come up to the great places of the world. Race suicide, if it existed, would be found in

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unsanitary conditions of life and in the recklessness by which children are often born into the world.

The best definition of efficiency, if it is to be used as a measure of civilization, has an ethical as well as a material sense. Germany has undoubtedly made an enormous advance in material wealth and in the applications of science. Her ruling classes have also provided for the welfare of the masses, perhaps better than any other nation. It is the concession that they had to make in order to keep a large population contented with their lot. That is their share in the government. But Germany is not efficient in the best sense of the word. Her scholars and her statesmen have betrayed her. One has only to read the paper signed by a number of professors to reach the conclusion that there is too much professor in Germany and too little humanity. The world has been hypnotized up to within a very recent period by Germany's own claim of preëminence, and the shock of this war's disclosure is as much a sense of disappointment as it is a revulsion against the professors' claims.

SOME WOEFUL GERMAN WEAKNESSES

Germany is not efficient in her relations with other nations. She is not even efficient in her spy system, for her spies are but children in the hands of Americans. Germany is not even efficient in her science and literature. She is woefully behind the English and the French, except in those applications that bring wealth and power.

In some article President Eliot has well stated what he calls "the precious lesson of the war." "Toward every kind of national efficiency, discipline is good and coöperation is good; but for the highest efficiency, both should be consented to in liberty." We are now going to prove this with the blood of our sons, and unless we succeed against Prussia our constitution will be subject to modification, and we must begin again, like Sisyphus, to roll the rock up the hill in the hope that next time it will not slip away from us to roll back.

A power of initiative in a free government and a power of initiative of its citizens are certain, in the long run, to triumph over a national organization created by a few who have carefully directed the thoughts of the masses. If we put Kaiser Wilhelm alongside of Abraham Lincoln, we see in his royal person only a belated barbarian come back out of a shuddering past to destroy all that humanity has gained in the fight against slavery. We know that the heart of

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man beats for the freedom of the individual, and that only the drum beats for the divine right of kings. Not one word that Lincoln has uttered is false to the doctrine of Christ. Scarcely one thing of the Kaiser's might not have been said by a heathen king. The whole Christian religion is based on the right of the individual to a life of his own, subject to a true adjustment to the Almighty's laws. Democracy is a final form of government. It may have its failures, and if it fails now it will come again and again until the whole earth is freed from privilege by birth and the rule of a few.

WHAT AMERICANS ALSO LACK

All preparation for public service must be based upon a foundation of good citizenship in our whole country, if our officials are to serve well in this republic. A human pyramid can be formed only with strong men at the bottom, and no first-rate public service can ever be built up on a flabby, careless attitude toward civic duties. America is young yet. It is like a boy who has grown far too rapidly, loose-jointed and tall, with unlimited possibilities after his frame shall have been knit into a solid mass. One hundred and twenty-eight years is not enough to bring a nation to its majority, especially one made up of such diverse elements as ours, the dumping ground of all the world for the oppressed and the poor.

Our neighborhood and our international ideals are sound. They are found in the Bible. At the same time we lack cohesion and public conscience in relation to our own Government. Every individual must be regarded as part of the public service, and the first thing he must acquire, whether he be native born or immigrant, is public conscience. In some way the ordinary citizen too often argues that because this is a government by the people and for the people the state owes him something. In that respect our patriotism is in part a sham, and we have plenty of evidence to prove it. A considerable fraction of the annual appropriation in Congress is the result of a trade among localities, each of which wants something out of the general treasury. The pension bills have been only too often a sop for voters, and capital and labor have already shown us more than once how little they care for the great mass of people whom they class as the public. In the lynching of criminals, and sometimes of innocent people, we find nothing but a total disregard for the good name of the state. These are our failures and we must get rid of them, in order that the beauty of democracy may not be hidden beneath its excrescences. In the matter of public conscience

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we need a religious revival, and the churches ought to take a share in this. It is their task, as well as ours, to lift this side of our national life.

ELEMENTS OF AMERICAN CITIZENSHIP

The first demand of our republic is, then, an educated public conscience. No man should expect more from his country than he is willing to give it. Those who whine about injustice in modern society are usually getting about what they deserve.

The second demand on every citizen should be a knowledge of our institutions and the method of government. It goes without saying that the English language is an absolutely essential foundation for this. Most failures in citizenship proceed from ignorance and carelessness rather than from viciousness. The normal American is right-minded and is morally upright but slack in his responsibilities to the public. The moonshiner in the Cumberlands makes whiskey because he neither knows his relation to the body politic nor the evil effects of drink. His whole conception of government makes it something separate and apart from himself, an attitude of mind that, if carried to its logical conclusion, breaks down all government and ends in the ghastly travesty set up by the ignorant peasants and workingmen of Russia under the corrupting influence of the Germans and of money. The first thing to learn is that freedom does not mean emancipation from all responsibility to others. It means the self-control that permits reasonable surrender to the needs of all men. War has given America the dim vision of a new freedom. In the fall of 1914 no one would have thought it in any way akin to our Civil War, and yet we see it now in its true perspective as the great struggle for freedom, as the struggle for the union of all nations, so that war may never come again. Yet we must have no illusions. Rousseau's doctrine, that man is born free, is false unless the word "free" is defined in some better sense than that in the dictionary. Men are never free. From the cradle to the grave they have to yield, and every individual lacks freedom in just the proportion in which he has to learn to live with other people. He must think of the wishes and the interests of others. When he has learned how to surrender himself and has learned obedience to the law, then he is truly free. Freedom is no more a natural inheritance than flying or riding a bicycle, but it must be learned if it is to be of any value in a republic. It demands training, hard discipline, self-sacrifice in daily life, especially on the part of those who are

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chosen to transact the great business of the nation and to lead in the maintenance of our democratic government.

Another much misunderstood word is "equality." In its distorted sense, it has encouraged that fatal kind of socialism that would permit no individual to stand out from his fellows in mental or material possessions, and it would eventually kill any form of government; for a nation grows great only on its inequalities, if they be not the type that set up false standards and destroy the soul. The true application of the word is found in opportunity. We are equal, and we ought to be equal as to the opportunity to make ourselves mentally and morally superior. We glory in the greatness and superiority of Abraham Lincoln, and in that equality of opportunity that permitted him to go from a log cabin to the White House. Our most important lesson, then, in connection with American institutions, is the meaning of the two words "free" and "equal." Only when every man, woman and child understands them will democracy be safe.

I venture to state that only a small fraction of the people in the United States know anything about the growth of the Constitution or the reason for adopting the articles fixing a definite relation between executive, legislative, and judicial functions. The Supreme Court has been called the greatest instrument for free government in the world. Why? The most powerful element of citizenship is found in the answer to that question. It involves obedience to law, respect for judicial decisions, and the supremacy of reason over brute force. How many of our citizens grasp the significance of this in the training for public as well as private virtue? It is second only to conscience in the making of good citizens and an atmosphere in which the public can be properly served. The two, conscience and civic education, create the kind of patriotism that would lead a man to refuse a public office for which he had no training. Such a thing as a cabinet officer's resigning because he turned out to be a misfit is unheard of, either because we have not learned what a misfit is, or because our people have not been taught what to give of themselves and what to demand in Washington.

The third element of citizenship is found in true history, not that garble of victories in war calculated to fill the breast with false pride that cannot see over an imaginary wall surrounding county, state, or nation. Germany is a victim of exaggerated ego because her historians and writers have totally misrepresented the place of the German in modern life. God has not selected any nation for

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the dominion of the world. His laws undoubtedly have established ideals that dominate humanity, but never for the purpose of surrendering to some brutal ruling class domination over men. Bad history, then, may promote bad citizenship. The history of our Revolutionary War usually emphasizes Bunker Hill and Yorktown at the expense of a proper perspective of the tremendous struggle against autocracy and the divine right of kings culminating in the French Revolution. We were fighting against George III and his Germans from 1776 to 1783, and the Declaration of Independence probably had more friends than enemies in England. The outcome of the Revolution was in the interest of democracy for the entire Anglo-Saxon race. It remains to be seen whether this war is the final blow to the old system or not. We might paraphrase Lincoln's words by saying that the world cannot longer exist half democracy and half autocracy. We must smash the autocracy in order that the world at large may recover a conscience and nations may hold a true and wholesome relation to one another. This is why history should be more carefully written and better taught in our schools.

A fourth element toward the foundation for public virtue in office is the education of foreigners in true Americanism. There are millions who must be turned into the kind of citizens found in the old colonies, the men who laid the successful and enduring foundation for free government. Could the American Constitution be written now? Have we the public men capable of striking off such a document? I believe we have, and that many of them have been created out of the children of foreigners. Through our workshops and our schools, and through associations, we should teach ideals of citizenship. This is more important than importing into the United States great examples of art in Europe. The statue of Frederick the Great set up in front of the War College in Washington is not a good example of citizenship. His system has ended in teaching good men that brutality is better in the will to force their *Kultur* upon other men than gentleness and love, and his work must all be undone if our conception of human freedom is to be extended over the whole earth. The perpetuation of German or other foreign societies in America is unthinkable, and we ought to break that down in one way or another. Usually the peaceful education of children in our public schools is the best method of proceeding. But we have not done enough by other methods. There should be a great organization within the United States for Americanism, and it ought to be used to counteract all other influence by

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public speaking and by a more effective propaganda than the Germans can ever again set up in America. This is the melting pot, and it is our duty to make sure that, when the whole mass is fused, it remains an American democracy firm in its convictions and in its demands on public service.

WHAT IS PUBLIC SERVICE?

What is public service? Almost everything we do that brings us into contact with our fellow-man is public, and we are likely to be too narrow in our definition.

Our relation to the government may roughly be divided under four heads:

1 The civil routine or conduct of business in government
2 Civil research and publicity for the benefit of citizens
3 Military training in peace
4 Military training in war.

THE CIVIL ROUTINE OR CONDUCT OF BUSINESS IN GOVERNMENT

This necessarily includes everything relating to the administration, Congress and the judiciary. It is remarkable how little appreciation our people have of Government business. No firm or corporation could exist under the present system in every department at Washington. In many cases the appointments, even when based on civil-service examinations, have not sufficient reference to the work to be done. In the higher offices, like the men who constitute the cabinet for the advice of the President of the United States, it is often only by chance that a man well fitted for the position is appointed. The War and Navy Departments may be included under the civilian departments so far as the secretaries and the clerks are concerned, and it is the rarest thing in the world to find, for instance, the Secretary of the Navy who knows anything about his business. Many million dollars and four years' incumbency are usually required to educate the man in office, and at the end of that time he goes out. Even though a few of the cabinet officers may fit into their positions, fewer still have any knowledge of government or the science of government.

When we come to the legislative branch the matter is even worse, because men are elected to represent constituencies on issues that have often no relation whatever to the transaction of the Government's business. Congressmen when elected have their principal

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interests at home and very generally do not feel under any obligations whatever to make a study of government. Their votes are cast too often without knowing anything about the subject on which they are voting. It may be said that this is also true of legislative assemblies the world over, but it ought to be better under a democracy that throws responsibility on the individual, the responsibility for fitness and for citizenship. The lack of conscience in connection with our legislation is often disclosed in the Congressional joker. A bill that has passed the House of Representatives and the Senate may go to conference on some differences, and there have inserted by some congressman either without intelligence or without conscience certain things that were never in the original bills and never had been discussed. In our appropriation bills there is wholly a lack of system. Attention has been called to this time and time again by men who have held high office and are well acquainted with our methods. Millions of dollars are squandered because there is no budget and no plan, just as millions of lives may be lost through the failure of concerted action by the Allies in this war.

Another feature of this shows a lack of understanding on the part of our people or a lack of enterprise on the part of the engineering profession. A very large part of the business of this country relates to industries, transportation and engineering enterprises, and yet there is hardly a man in all Congress who has any grasp of the engineering matters. The curious part of all this is that our Congress does not know that it doesn't know. What would be self-evident to a scientific man must be beaten into a congressman by means of a trip-hammer, and yet our people put up with it!

We have every reason to feel confidence and pride in our judiciary, so far as the Supreme Court judges of the United States and of the states are concerned, but the courts have already been too much criticized by their own judges and lawyers to render it necessary for me to make any explanations whatever on the lack of training for doing business. Many cases have been known to hang on for years. Trials that should have been dismissed in two days have been exploited before the public for weeks. The Thaw case that was tried in New York was a disgrace to any community. The newspapers without public conscience at all published broadcast the most nauseating details calculated to satisfy only a morbid curiosity or to degrade the moral and literary taste of our youth. The difficulty with this is that the courts permit it to continue on the ground that the newspapers publish what the public wants—

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the same ground that would permit the sale of poison because the public wanted poison.

RESEARCH AND PUBLICITY FOR THE BENEFIT OF CITIZENS

In our scientific departments of the Government we have in a way emancipated ourselves from the accusation of inefficiency, although much useless stuff is published. The Bureau of Standards, the Agricultural Department, the Geological Survey, the Bureau of Mines, are unquestionably helping to educate our professions, our workmen and our farmers into higher efficiency. The men appointed to office under these different departments are usually well-trained men. They can naturally be classified by some kind of civil-service examination as the men in the business departments cannot.

Every state and every community unquestionably feels the effect of what we may call publicity at this time. The food-conservation program carried out by a mining engineer is really creating a revolution because the American people have been exceedingly wasteful and they are learning now something of the moral effect of saving. Mr. Hoover is only an instance of what can be accomplished by putting a trained man at the head of a department. Mr. Scott at the head of the War Industries Board and Mr. Coffin at the head of the great industrial survey, were other examples of what our profession may contribute to the success of the Government. Too often, however, the profession of engineering does not realize its usefulness. We belong to all departments, those of business as well as those of scientific research, but it is the latter that claim us and we should be ready at all times, for this our highest function in the service of the people. Few engineers confess themselves able to speak on engineering and governmental subjects. We hold a duty to this republic, and we ought to fulfill it by learning.

MILITARY TRAINING IN PEACE

One of the most astonishing phenomena in modern times is the ease with which the conscription bill passed Congress and the extreme ease by which it was enforced. Practically no objection has been raised except by a few malcontents and crazy people, and yet a few years ago no one was ready to listen to the words *military training*. Perhaps the speakers on the subject emphasized the words too much and gave the impression that they meant a large standing army, which we shall never want. If there is to be service

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in war, the whole nation, every individual, man, woman and child, must share in the sacrifice, and must be prepared. The hiring of volunteers is no longer moral. Only time will indicate how much we owe to Leonard Wood for his untiring effort to wake up the country to the importance of military preparation. The whole matter of training officers has been formed directly around his Plattsburg camp, and it is not too much to say that the training of all our men for service abroad is based on his theories. We listened too closely to the politician a few years ago and we have been fed up with three or four thoughts that would destroy the discipline and the correct reasoning of any nation if that nation believed them. The springing to arms of a million men in a single night is that peculiar kind of idiocy that is accepted in the remote agricultural regions where ignorance of history is the dominant note. We engineers are not too proud to fight. We do not want peace without victory. We were not kept out of war and we do not want to be kept out until little Belgium has all that belongs to her again, all except the dead and the virtue that has been outraged by a brutal soldiery. I have never been a believer in the German system, because it gave too much control into the hands of a comparatively small number of officers constituting the German general staff. The idea of service beneath that system is, however, good. It makes for the education of young men and for obedience to law. Our country is not built up on the idea of obedience to individuals. It should, however, learn that liberty is based on law, and can never be anything else. It is hardly necessary at this time to dwell long on military training in time of peace. We have had our lesson and we shall probably never go back to the old system of a small standing army and a smaller militia of more or less efficiency, usually less. The conception of public service has been drilled into the people by stern necessity to maintain the liberties of the world, so that we shall probably have some kind of military training long after this war is over. Everyone has noticed what a difference the camps make in the slouchy individual who enters, to come out the trim, erect soldier.

The old pioneer days when every man was trained to use a musket have long ago passed, except in a few places not yet settled. We cannot possibly depend on the initiative of communities to teach our boys how to shoot, and in fifty years from now a gun of any kind will be as little understood as the archaic engine put into operation by James Watt. Consequently, we must necessarily have

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some artificial methods of teaching the youths how to shoot and how to act in coöperation with other young men.

Military training is probably the best method we have of Americanizing the young men who come to us from foreign countries, and every one of them ought to be required to take his turn of service. It is not necessary that a foreign citizen making his home here should be required to bear arms against his old country, but he should, for the sake of teaching him American ideals and American institutions, be obliged to take his place in the camps with young Americans, if he is permitted to make his living on our soil. The simplest of military training is learning how to keep step, and that is a great moral influence. We need it beyond everything else in this country, where the forces are so pronouncedly centrifugal. Keep step! That does not mean that the men have to think alike. It does mean that they must act together for the good of our country, by a willing obedience to the control of men selected to manage the affairs of Government. Keep step! The great leveler between the rich and the poor who must work together, whatever their homes may have been. It is the great simplifier of human relations. Keep step! The collective action that will put our public servants into a higher standard of training and education for their jobs. Keep step! There is nothing more inspiring, more beautiful than the march by of an American regiment. There is no goose step about it. It is the free swing of a free people that will never be trammeled by military dictation.

MILITARY TRAINING IN WAR

This nation already has that definitely planned out and our conscription bill has called many thousands to the colors. The selective feature of the bill has been more or less lost sight of, and its spirit has been violated up to the present time. Selection on June 5 amounted simply to a lottery method of choosing men for the service, and little attention was paid to selecting them for special positions in such a way that an army might be formed most quickly. Our young men are graduating from the schools, colleges and technical institutions. Many of them have a training similar to that found at West Point and Annapolis, but comparatively little use has been made of this fact. There are new training schools established that will eventually turn out men for specialized service, but here are, and were, many young men all ready for special service flung into the ranks. We have had warning of this in the mistakes

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of England at the outset of the war, and we have done nothing about it until now. One of the very curious anomalies in connection with even temporary exemption, is found in the recognition of the special importance of dentistry and the study for the ministry, while the industries have been recognized only so far as their workmen are concerned. If the present system is maintained, our engineering colleges are going to disappear in a comparatively short time, and the Government will have to set up special schools which will take years to fit men for the places that the engineering schools can fill. Training in war is very quickly seen to be the heir of mistakes in training during peace. Inasmuch as we had no training before this war came on, we are heir to nothing and all of it will have to be learned.

The most serious part of this whole business is that training in time of peace is of no use whatever unless something is done about a supply of munitions and weapons to be used in time of war. In that respect we were worse off than any of the belligerents except little Serbia or perhaps little Portugal, whose standard we just about reached at the outbreak of the war. That is what rising over night with a million men always means in the mouth of those ignorant of history, even though they be in high places.

GREATER WAR PUBLICITY NEEDED

The training for the present war has a very important corollary that we seem for the time being to have lost sight of. A press bureau is established in Washington for the dissemination of information and its duties have been too narrowly defined. We need now extensive propaganda on what we are actually fighting for. The President well stated the case in his reply to the Pope's proposals for peace, but the people know only the call for troops and for money. A few pacifists and their friends the German traitors are concealing the great moral issue behind this business. We must have concerted and widespread publicity of a more penetrating kind. What do the Central Powers stand for, the Prussians, the Germans, the Hungarians, the Bulgarians and the Turks? They are all banded together under the compulsion of the Prussians, whose ideas of war as a good thing and brutality as the justifiable method of striking terror into the rest of the world are wholly abhorrent to us. Their success means our failure, and we must bring this home to every American instead of taking things placidly while the German newspapers are fooling the public. We must, as engineers, carry back

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home the determination to awaken the country whether we are organized for that purpose or not. Every bit of camouflage should be torn off so that we Americans can see the vision of death beneath it. The old Persian proverb, "He that knows not and knows not that he knows not, he is a child, teach him," tells us the daily work of all our spare moments.

As part of the general publicity we must dwell on saving for the war. Economy in food, fuel and clothing is the moral duty of everyone. One of the saddest sights in an American community is the organization of merchants to tell people to go on in their former mode of life and to buy. Carry this idea to its logical end and we shall lose the war. Prosperity has not come. All boosting of prices is blood money, and the men who are taking advantage of the country's need will be tainted all their lives. One of the most necessary distinctions in business is the priority of essential industries. All unessentials must go and all excess profits must be saved for the success of the country in war.

ENGINEERS MUST KILL CONSPIRACY

The twentieth century is still young, and we do not yet know what it will represent to the future historian. Will it be the debauch of science or will it mean a new birth to Christianity? It is our task to decide this. There are two tendencies: one toward greater comfort and luxury, and one toward greater service. The first can plunge us only deeper and deeper into war for the control of a commercial output. It can only bring us more firmly under a governing class derived either by birth or by commercial success. The second means the complete emancipation of the individual trained to think of service as the chief source of good government and happiness in life. The only theory that will hold men together is that of service. All others, like the control, for instance, under an overlord, are but the cracked shells of old doctrine. This war is their last stand against a modern world, and our work as engineers and citizens is to help prepare for the new day when the rule of kings shall have been swept away. Our profession has been morally responsible for America under the century of invention just passed, as it is we who have created the applications of energy and it is we who have given the wealth of the world into the possession of a few men. This war will create many millionaires. It will place vast power into the hands of the strongest and most ruthless. It will strengthen the trade unions into autocratic groups defining

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what each individual shall be permitted to do and what wages each shall receive. Are we to stand by and accept this? Are we to remain forever blind to our own power? There is only one answer to that. We must, as engineers, go forward with our own countrymen to kill this conspiracy against freedom, and then we must give our lives to fight that science may never again be employed as a destructive agent in the hands of a few unscrupulous men.

WHAT CAN OUR SOCIETY DO?

What does our Society stand for in the scheme of this world's affairs? We know that there must be more or less selfishness and there will be often a great difference in the general fundamental principles underlying organization. Coöperation may have as its motive one of two ideas: first, the desire to benefit others, and second, the desire to benefit the organization. Sometimes it is difficult to classify under either of these, as the benefit to an association is often a benefit to the public, in lifting the general average. And yet when things are traced back to their origins, it is possible to place most associations in their true category. For instance, the missionary societies — and we may with equal propriety say the churches — are altruistic in their origin, and, in the main, they remain so. Charitable organizations, hospitals and colleges are unselfish, and grow out of a sincere desire to give one's self to the service of others. Our own Society belongs to that class which benefits others as it benefits itself, for it is essentially educational in its purpose. As the years have passed we have come nearer and nearer to a true conception of what our public relations should be, and this war has brought about a sudden large vision of our duties. They are not to be found in reforms put forward by the weak, or by self-seeking manipulators of public opinion, either within or without our Society, but rather through a state of mind. We owe it to our country to think clearly and rightly, and to throw the whole weight of our Society into the scale for sound legislation, good government, and public conscience. The engineer's philosophy is shown in his actions rather than in his words, because he has never learned to explain himself. It is expressed in the desire to serve. No profession can claim a higher motive than the silent men who fill our ranks.

We believe our Constitution to be the best instrument of government ever produced, and that under it all mistakes and imperfections tend to correct themselves. Our advantage is that conspiracy

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can never thrive, and there can never be a policy fatal to other nations. We can discuss any question of national policy and we can always have publicity against any hurtful tendency. The newspapers have always exhibited a high degree of patriotism when the need came for discretion, and we may depend on them in times like this to stand behind every program for the good of our country. However sensational the headlines may be, we know that behind them is always a sincere desire for the greatest good to every citizen. Whatever our faults may be, they are always in the open and, like bacilli exposed to the sunlight, they die. That is, after all, the reason why a republic or some form of democracy is always superior to an empire under a few men.

Our country is the home that we love and, as engineers, we must feel a deep responsibility for its welfare. It is given into our hands by our forefathers and we know its virtue, and, God willing, we shall strive to make it the perfect example of what life on this planet shall become when wars are past.

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No. 1602*b*

THE ENGINEERING SOCIETIES IN THE NATIONAL DEFENSE

By Gano Dunn, New York, N. Y.
Member of the Society

ENGINEERS are, indeed, coming into glory and honor — glory in the things we were reading about in yesterday's and to-day's papers as to the behavior of the very men whom our national engineering societies recruited New York through the agency of the Military Engineering Committee only a few months ago, and honor in the ways that were referred to by your President in his address, in which he mentioned the fact that the engineering profession and the corporate societies representing them are having an ever-growing opportunity to "do their bit" for the Government at this critical time. The spirit, the intelligence, the usefulness of the engineer is a matter of common comment. I have talked with several university presidents who remarked upon the high percentage of enlistments and volunteering for service, particularly of the men in the engineering schools, and Dr. Hollis has not exaggerated the part that engineers are playing, and are yet to play, in respect to the things in this great war which we have only just begun to appreciate and understand.

I should desire this morning to bring to your attention some of the things that are now being done by engineers and engineering societies. Adequately to treat of what the engineers are doing would take days, if not longer, and I can only refer to it. One has only to be in the atmosphere of Washington a short time to see that the whole Government of the United States in respect to its military and naval preparation rests upon a foundation of engineers.

My task is encyclopedic, and I beg your indulgence if I but hastily skim over it. I wrote to the representatives of thirty-two different engineering bodies that are now in contact with the Gov-

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ernment, asking them to give me authoritatively, although briefly, a résumé of what they were doing in connection with the national defense and with the war. It is beyond our time for me even to go through the replies, but I hope to put them in the record, and they are certainly a scroll of real honor to our credit.

To begin with, there is the Naval Consulting Board. The Naval Consulting Board was intended to bring formally to the service of the Government the scientific and technical ability of a group of the best advisers on engineering lines in the country, and the Government had the conception that if it asked the engineering societies to select these advisers the selection would be better made than if it itself attempted to make the selection. Consequently, two representatives from each of the different engineering bodies were nominated, and under that nomination appointed by the Secretary of the Navy, and that board has been doing able service since the time it was appointed, starting with the Committee on Industrial Preparedness, which took an inventory of all the industrial resources of the United States. Later it proceeded to report to the Government on the needs of the experimental development of improved devices, and finally it established connections whereby its services might be made available and useful to the army as well as to the navy.

It now holds an honored position in Washington, where it acts as a Board on Inventions, and substantially all newly invented devices that are brought to the attention of the Council of National Defense, through various channels, are now referred to the Naval Consulting Board to be passed by, or turned down if they are not useful, or given attention if they are valuable. The Naval Consulting Board has offices at 15 Park Row, in New York City, and has a large force of clerks. The devoted services of its members are constantly given to going through thousands upon thousands of suggested devices from engineers, citizens, and others all over the country.

The Naval Consulting Board was created long before the war. The next body in order was the National Research Council. The National Research Council was started because it was seen that, just as in the Civil War, such help as was given by the National Academy of Sciences, created by President Lincoln, and is now being given by the national engineering societies, would be again needed. The Government acted, therefore, under the charter of Congress granted in 1864 to the National Academy of Sciences, among the provisions of

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which were the requirements that the members of the Academy who then represented what we now represent, the engineering as well as the scientific intelligence of the country, serve the Government on request, in whatever direction called upon, without compensation. And they did an unusual amount of service at the time of the Civil War.

Between that time and now, entirely aside from their scientific functions, they have reported on about sixty different questions to the Government. It was seen that this body could be made of great use at this time, and consequently President Wilson requested that it enlarge its scope and bring itself, as it were, down to date, and include the increasing branches of science that were not known in the old days, including engineering, and to do everything to put at the service of the Government the scientific talent of the nation.

In accordance with this request the National Academy of Sciences organized the National Research Council, which may be described as being partly a federation and partly a creation, through which there comes to one single focus every important scientific agency in the United States. It reaches the universities, it reaches the industrial laboratories, it reaches the engineering societies, it reaches the isolated workers in pure science, but the keynote of the National Research Council is science rather than engineering, and engineering plays a part in it only as it deals with pure science and applied science — in short, what we call engineering research.

When the war broke out it was only natural that the Council of National Defense should request a connection to be made between that body, which had existed for nearly a year, and itself, and since the war the National Research Council has almost dropped all other activities and directed its whole efforts to the problems in science that have been handed down to it by the Council of National Defense.

The next body in order of creation was the General Engineering Committee of the Council of National Defense. When the war broke out, our Society, in common with other engineering societies, immediately, and with a patriotic devotion, offered the services of engineers to the United States, directly to the President; and I do not think any of us realized at that time just what we were offering — quite a little confusion has arisen since as to what it was, but I do know that when we made the offer we did not intend to limit it merely to our engineering services, but we meant to go to any lengths that might be necessary.

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Later on it came to be obvious that through this offer to the President we had not intended to convey the offer of our military services, and among other things we all remembered then that we were members of an even greater society than The American Society of Mechanical Engineers, we were members of the Society of American Citizenship, and that through membership in that greater society there came to us calls for military services and other things, and consequently the offer to the President of the services which we made through our Society was regarded as conveying only the offer of engineering services.

The President turned our offer over to the Council of National Defense, and from Dr. Hollis Godfrey, of the Advisory Commission of the Council, an invitation was received to appoint representatives to form an Engineering Societies' Section of the Engineering Committee of the Commission. The Society acted officially upon that invitation and sent representatives to a conference in Washington, who met together with representatives from other societies.

From my point of view, this General Engineering Committee as it stands now is the official connection of our societies with the National Government; but the spirit among the engineers who want to serve the Government in more ways than this Committee renders possible, has caused the springing up on all hands of numerous other committees. I am going to read to you a list of the committees of engineering bodies which were in existence at a time, a short while ago, when outwardly and from the point of view of the Government there seemed to be so many committees that they were crowding each other, overlapping, and in their actual relations to the Government carried with them a certain degree of possible confusion, which was brought to our attention and which some of the members of our societies have been endeavoring to remedy.

These committees or engineering bodies are: Naval Consulting Board, American Engineering Standards Committee, Engineering Committee of the National Research Council, Commitee on Gas and Electric Service, Emergency Construction Committee of the War Industries Board, the Intercollegiate Intelligence Bureau, the War Committee of the Technical Societies, the Engineering Council, the American Engineering Service Committee, the Aircraft Production Board, the Aircrafts Standardization Committee, the Aeronautics Committee of the National Research Council, the United Engineering Society, the Engineering Foundation, the American Society of Civil Engineers, The American Society of Mechanical Engineers,

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the American Institute of Mining Engineers, the American Institute of Electrical Engineers, the American Society for Testing Materials, the American Society of Automotive Engineers, the American Electrochemical Society, the Illuminating Engineering Society, the American Chemical Society, the American Gas Institute, the American Society of Refrigerating Engineers, the American Water Works Association, the National Electric Light Association, and the Association of Edison Illuminating Companies.

The mere enumeration of these engineering bodies itself is a bright light on what the engineers as societies have been doing for the Government. It does not begin to be a token of what engineers as individuals are doing for the Government.

As societies, however, there has been some confusion among the various societies, due to overlapping, and there has been also some lack of distinction between engineering services on the part of individuals and corporate services on the part of societies. For instance, one of the great services which no single individual could render the Government, but which a union of societies could wonderfully render the Government, is the question of engineering personnel. So great has been the demand in Washington for competent engineers for this, that and the other service that they have not known where to go to find the men. They first went to their personal friends, to the members of the engineering profession already in the departments, and to those whom they were acquainted with, but soon the supply of acquaintances of these men and the men with whom they were in contact was exhausted, and the authorities were simply at the end of their capacity.

It has been very obvious that at least one of the functions that the national engineering societies could perform was to serve as a center to which the Government could go and find an adequate, properly classified roster of all of the men who could render service to the Government, so that the services of these men could be promptly called upon. Through a misconception, the responsibility for which I will not attempt to go into, the General Engineering Committee, which, as I have said, in my view is the official connection of the societies with the Government, declined to furnish the required roster of the personnel. I ought to say that it declined to do it on the recommendation of its chairman, Dr. Hollis Godfrey, who at the time was under some instruction from another branch of the Council of National Defense, which had in view the classifying of engineering service or labor generally, and consequently

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had in view the grouping and listing of this service in another department of the Council of National Defense, where it was hoped there would be a much broader and more general listing of labor than that which we now usually consider as labor; but be it as it was, the General Engineering Committee declined what, in my opinion, is the principal opportunity to be of service to the Government.

There then sprang up the Intercollegiate Intelligence Bureau for the purpose of making good this deficiency to a certain extent. Its origin was not in the engineering societies, but through an engineer, one of the prominent members of the American Institute of Electrical Engineers, Dr. William McClellan; he organized 170 colleges into a sort of league to supply to the Government men of technical training and engineering qualifications. He went at it through the colleges, because he is president of the Wharton School, and also because he felt that through them he could get in contact with a greater number of engineers and could accomplish better work than in the other direction.

The Engineering Council, which is a body destined to represent not only the great national engineering societies which are members of the United Engineering Society, but all of the great national engineering societies, also took up the question of personnel. It conceived its function to be a very broad one and organized in an endeavor to make certain contacts with the Government, leading up to that through the Naval Consulting Board, through the National Research Council, and through the General Engineering Committee; and there was also created under the Engineering Council the War Committee of the Technical Societies, and also a committee known as the American Engineering Service Committee; Dr. D. W. Brunton is chairman of the former and Mr. George J. Foran, chairman of the latter.

These committees went to work vigorously, headed by Dr. Hollis in the Engineering Council, and from the beginning have seen the importance of a registry of engineers and they actually started to accomplish a registry of that kind. When representations as to what these committees had done and were doing were made to the Government — and now speaking from my own point of view, and with the hope not of producing controversy, but of allaying it — the committees were not fully aware of what had been done already by the Naval Consulting Board, by the National Research Council and by the General Engineering Committee, all of which

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bodies had been in efficient contact with the Government, contact through channels that had been grooved more or less bright by use; and therefore the newer committees wrote to numerous agencies of the Government and interviewed them, and from the Government point of view canvassed the Government as to what channels they should use in their relations with these various activities.

The confusion that arose, although not serious, required straightening out. For instance, the national engineering societies, as such, had nothing to do with the appointment of the National Committee on Gas and Electric Service of which John W. Lieb, Mem.Am.Soc.M.E., is Chairman. They were more or less unfamiliar with that committee and its work, yet of all the committees in Washington that committee has probably done as much as, if not more than, any other committee in specific and concrete service rendered to the Government. That committee is a committee representing public utilities, or rather it represents the Council of National Defense — it is a committee of the Council of National Defense itself — but it instructs them and knows about the public utilities, and so today is charged with questions of coal supply and of power supply, questions of keeping the industries going that are engaged in munitions manufacture, questions of cantonment inspection and cantonment supplies.

The gist of the matter was that a certain member of our Society, Mr. Swasey, the Father Abraham of the engineering profession, was down in Washington and learned of some of these things. He endeavored to bring about coöperation and understanding among the thirty-two different engineering agencies. He called a meeting of the representatives of these organizations, and they all most promptly responded and met in Washington. That meeting was an eventful one in the history of the relation of the engineering societies of the country to the Government, for the knowledge was there brought out of the vast amount of service that was being rendered to the Government by engineers, and everyone present at that meeting was astounded at hearing how much everyone else had been doing, and the mere getting together of these committees is a thing that is going to solve the temporary and minor difficulty of a unified relation of the engineering societies to the Government.

For instance, at that conference we heard the representative of the Society of Automotive Engineers say what his committee had been doing. That society has been intensely vigorous — it has been of actual, concrete and real service to the Government in a way that cannot be known; in fact, one reason why the members of the soci-

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eties have felt impatient at their Washington relations is because the work, as such, cannot be dwelt upon in detail among them. The Government requires that almost all the work of these various committees and societies be confidential and shall be kept to themselves, and that is one reason why the membership of the societies have felt that they were not doing their bit, when in fact they were doing all that the Government so far had called upon them to do.

The status of the matter at present is that that joint meeting in Washington appointed a sub-committee to confer with the Engineering Council and with the governing bodies of the national societies, with a view of reporting back some general plan whereby the chairman of the War Board, for instance, would not be receiving four different letters from engineering bodies, each inviting him to take up problems of a certain kind through that particular committee. It is confusing to that chairman to receive such letters, and, moreover, it shakes his confidence in the ability of the engineers to organize their work effectively and to do the things that they most want to do.

I am afraid I have omitted ninety per cent of the things I wanted to say in regard to the activities of certain of these committees, and I perhaps ought to speak about the War Committee of the Technical Societies. That committee was intended originally to be a vehicle of information between various Governmental activities and the membership of the national societies. It was intended to be of service both ways. It was intended to satisfy this demand on the part of the membership by knowing as far as possible what was going on. It has recently established a connection with the Naval Consulting Board, and the general view of the engineers now interested in the Washington relations is that there never can be too much service in Washington, and that there is room for every committee. Colonel Carty, who presided over the conference called by Mr. Swasey, said that the whole thing is too big to be controlled by any one committee, and it is realized that the more there are of these committees that represent real service, the better it will be, and all that is needed is a little better directive force and a little more inquiry and coöperation before taking up with the Government questions that may have already been settled, in fact, by other agencies.

The situation as it stands now is one in which we may all take great pride. The General Engineering Committee of the Council of National Defense is in the awkward position of being asked by

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its chairman to resign. This is through, as I understand it, an early interpretation that service on that committee is incompatible with the ruling of the Attorney-General to the effect that men may not serve on committees of the Council of National Defense when they have other business relations with the Government. The business relations of the men in the engineering profession serving the Government are so numerous that if that principle were really carried out in fact, the Government would be deprived of the service of engineers; or, on the other hand, the industries, the engineering projects, and the very great works that are now being accomplished for the Government would be robbed of the directing heads that are producing them. Neither of these alternatives is for a moment conceivably possible.

This opinion of the Attorney-General has been later interpreted by the Secretary of War to mean that no man may sit on a board in Washington when that board is engaged in deliberating upon the award of a contract to a company in which that man is interested. That is only common sense. It has gone one step further, and says that no man may sit on a board when that board is making recommendations to another board, which other board may be empowered to award contracts, except in this case the man is not forbidden to sit on that board, but if he sits he must file with the second board a statement of his complete relation to the contract that is under consideration, and state what other interests he may have with it.

I think one reason for the general resignations that have occurred in the Council of National Defense has gone a good deal further than this technical situation. The Committee has been overgrown, overgrowth indicating rather a lack of authority, which the springing up of so many committees always indicates. The authorities wanted to reorganize the whole matter, and certainly that reorganization is now in force, but whether it will take the form of continuing to ask for the resignations of the members of the General Engineering Committee of the Council of National Defense, or whether that committee can be regarded as an exception, because it is a non-commercial committee, and whether that committee can be permitted to retain its relation there with the Advisory Commission, or establish new relations directly with the Council of National Defense — the same relation that has been established by the National Research Council — is not yet to be known. However, whatever it is, the principal thing which is now to be settled is not the relations of the twenty-eight of the thirty-two committees, whose names I have

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read; their relations are very satisfactory; they are doing splendid work for the Government; they are a credit to the societies that have created them and the men who are in them. They are one of the good right arms of the authorities in Washington. Any confusion that may have existed lies in respect to the relations of the engineering societies, as such, to the Government; in other words, our own corporate relations to the Government for those things which we as societies may do, which we as engineers do not do, and under the leadership of Mr. Swasey that general question is now being happily and kindly worked out and thought out in a way which will result in the Government continuing to get not only the service it has been getting, but such increased service as the near future will lead it to demand.

We are not yet really in the war. Times are coming — they are predicting it in Washington — when the service we have so far rendered will be like but a little cloud on the horizon. Our duties will increase; our opportunities will increase. I do not think the patriotism of the engineering societies can increase. It has been at par from the beginning.

But, gentlemen, those of us who felt that because they were not yet called upon they were not going to have a place in this great war; those of us who have felt that because of some defect in the machinery at the top they were not being put in touch with the things they could do; those of us who have felt that way, I think, will soon, and very soon, have a call for everything that they can render. In Washington the views of the authorities are all in one accord as to the patriotism, the usefulness, the distinguished service and the ability of the engineering societies and their representatives in the national service. We have been a credit to ourselves in a big and fundamental way, even if some of our superficial relations have not been quite as orderly as we might have liked to have them. I have been told there is not yet on record a single case where the Government has actually asked an engineer to do a service for it where he has not responded, and that is a badge of honor which for our profession I hold very high.

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No. 1602c

SPECIAL EDUCATION IN TIME OF WAR

By Charles S. Howe,[1] Cleveland, Ohio
Non-Member

THE problems facing the engineering colleges are definitely connected with two questions, which I do not propose to discuss at any length. The first is: Does the country need engineers in time of war? And the second is: Have we enough engineers now to supply the need during the war and after the war is over?

It would be needless to mention these questions were it not for the fact that if the present methods are carried out there will be no teaching in engineering colleges after a few months have passed, and the engineering colleges are the only places where systematic education in engineering is given. Engineering instruction is carried on to some extent in some shops, and very efficiently carried on, but there is no systematic attempt made over the entire country to give engineering education in the shop. Hence the colleges of engineering are the institutions to which we must look for engineers in the future if we need them.

It is surely not necessary for me to answer the first question after you have listened to the address of President Hollis and the address of Mr. Dunn, and it will be especially unnecessary after you have listened to the other speakers of today. I shall not attempt to discuss that question.

As to the number of engineers needed, it seems to me that all of you will agree with me that we do need to continue the supply of engineers, because we shall need more while the war is going on than we have now, and we shall certainly need them after the war is over. You have found in your business the drain upon the supply of engineers now. You know in a good many cases it has been difficult to get men for engineering work in the firms with which you are connected. We in the colleges know we cannot supply any

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of the engineers that are demanded now and asked for every day, that it is utterly impossible to send a man to any place unless we take some one who already has some position, and that the demand now is larger than it ever has been before, and we believe it is going to continue.

Therefore it seems necessary to train engineers for the future. But the drain upon the engineering colleges has been very great. As soon as war was declared it seemed as if every college student — I can speak only of the engineering colleges — wished to go into the army. We had very great difficulty in keeping any of them in the colleges. While they were determined to go, the members of the faculties were trying to keep them out of the army as far as possible, because it seemed to us that these boys who were being instructed to become engineers would be of more service to the country after they had been trained as engineers than they could possibly be as privates in the army. If the situation were more critical, if the enemy were at our door and every man had to shoulder a gun, the case would be different; but as things are now, and as the supply of engineers is limited, it seemed to us that we ought to keep these fellows in the colleges until after they had been graduated. But it was impossible to do so. They enlisted in every form of service — they went into the army, the navy, the flying corps, and the ambulance corps. They are carrying ammunition in automobiles all over the battlefields of Europe, and they are in every kind of service that the army has to do. They are going now in large numbers, and most of the engineering colleges have lost anywhere from twenty to thirty per cent of their men in the last year.

These figures merely include the number who would be trained as engineers and graduated within the next few years, but now, by a ruling of the War Department, young men have the privilege of enlisting up to December 15. After that date, if they are drafted, they must go into the service for which they are drafted. The result is that there is the greatest uneasiness among all college students. They are leaving our colleges in large numbers, and unless something is done to allay this uneasiness before December 15, we shall lose a large number of men who ought to go into the army as engineers.

According to the classification that has just been given out, college students will be in Class No. 1, and that class is to be exhausted before any other class is drawn upon. Consequently the

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engineering students will all be taken out of our colleges in the next draft unless something is done to save them for their professions. I would not at all say that the boys object to this — these fellows are young, they are full of red blood, they are interested in their country, they are anxious to have a hand in the struggle that is going on at the present time. They want to get into the struggle, and it is with great difficulty that we keep them out of it. But we who are charged with their training are trying to look at this thing in a cold-blooded way. We say, "Are these men going to be needed for a special service?" If they are, they ought to bear in mind that every man should look forward to the best service that he can render, and not merely try to get into some kind of service.

PLANS FOR DRAFTED STUDENTS

The colleges, recognizing the difficulty before them, have tried to interest the War Department in the question of saving some of these students, because after the second draft is made there will be only those under twenty-one years of age — and not even those, if the draft age limits are changed, as seems probable — and those physically unfit.

You are all probably aware that the medical profession took up this question last fall, and that an act was finally passed which permitted medical students to enlist in the Medical Reserve Corps, and the men who so enlisted are not liable to draft, are not liable to be sent into actual service until after they have secured their degrees, and so the Society of Amercian Universities has requested the Government to allow engineering and other scientific students to enlist in some reserve corps until after graduation. They have asked that chemists and engineers and physicists and bacteriologists and others pursuing scientific work might be allowed to go into one or another of the numerous reserve corps where they would, of course, be subject to Government control, but would not be called upon until after graduation. The authorities at Washington turned down this request. A similar request made by the Association of State Colleges, has not been acted upon as yet, but probably will be turned down, because it is similar in character to the request made by the Association of American Universities.

A request has been made by a number of colleges that students who are enlisted shall be furloughed back to their institutions. That has not been acted upon. It has been suggested to the authorities, I believe by army men themselves, that a certain proportion

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of engineering-college students be exempted from the draft until after graduation. Some of us object very much to that word "exempted." We do not want our college students exempted from service. We want them in the army, if they ought to be there, by the draft, but we would like to keep them in colleges long enough so that they may finish their training.

Another plan which has been proposed is that engineering-college students who are drafted be detailed back as drafted men to the institutions from which they came, provided that when they were drafted they were in a state of proficiency in their work in the college so that it is reasonably certain that they can be graduated with credit to themselves and the institutions with which they are connected. A part of this same plan would be to have these men wear their uniforms and have it understood by all of the students that they were soldiers in the army, and that the colleges be required to give them military drill, so that they would not be losing altogether the training which they would have had if they had continued with the active army.

Another provision is that the colleges shall report the standing of these men to the War Department at the end of each semester, and any man who is not doing efficient work shall be immediately sent to his regiment. Another provision was that after graduation these students should immediately go to their regiments as privates and work up to positions as non-commissioned officers and perhaps commissioned officers, if they were competent for that kind of service and were needed for it.

It seemed as though one or the other of these methods would permit us to keep our students in college long enough to train them for the various branches of service and that then they could be sent wherever they were needed. The Government has seemed indifferent to the necessity of maintaining the supply of trained engineers. I think that is because they have been so busy with organizing the army that they have not been able to give any time to the question of training the engineers. I was in Washington last Saturday with a committee of another society and took up this question with the War Department. It seems from what we learned there that the War Department is greatly interested in this question and is now taking steps to provide adequate training for a certain number of engineering students. The details of the plan we do not know — and cannot know until the matter has passed through the hands of the Secretary of War, but it looks now as if

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some method would be adopted at Washington before very long whereby engineering students may go on with their training, just as medical students are now going on with their training.

[In this connection it may be noted that the A.S.M.E., through the Engineering Council and the Society for the Promotion of Engineering Education, passed resolutions to the Government that the preservation of a source of supply of engineers be given careful attention. These resolutions were duly acted upon and provisions made for drafted engineering students. — EDITOR.]

SPECIAL TRAINING DURING WAR TIME

Another question which has been before us is that of special training during the war. I think that all of the colleges have insisted on military drill as part of their work. Many of them have made this training compulsory, although it has been exceedingly difficult to secure army officers to take charge of that drill. Nearly all of the colleges which could not secure army officers have appropriated money from their own treasuries to pay for the services of men who have had experience as officers and who are not eligible for active service in the army at this time. Nearly all of the colleges have established some military-engineering work. For instance, they have taught the students how to build military bridges; they have taught them how to lay out intrenchments; how to make rapid plans of any region of country; how to do reconnaissance work; how to make maps which could be used by the army officers of any section of the country, and various other things connected with military engineering which are very desirable for any officer and perhaps for any soldier to know.

Work has also been given to some extent in the mechanical- and electrical-engineering departments; that is to say, men have been trained in the application of electricity as necessary in the army. Some of us have gone to the military-engineering schools, where we have been able to find out just what instruction is given the army men in signaling, for instance, and in the use of searchlights, as well as in military telephony and telegraphy, and courses of study have been introduced in many of our engineering colleges to better prepare men for that class of work. The Chief of Ordnance suggested one day in Washington that the colleges give their students in machine design in the future the designing of heavy guns and gun carriages instead of the ordinary machine design, and

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offered to furnish blueprints which would form the basis of some of this work.

Some of our institutions will teach their chemists a great deal about explosives, giving them not only the chemistry of explosives but the methods of manufacturing the explosives. I do not mean that they maintain explosives factories on the college grounds — that would not be allowed — but they teach them the methods of manufacture, so far as they can, without actually manufacturing the explosives, and teach them the chemistry of all of the ingredients that go into the explosives.

Quite a number of professors of chemistry have visited the explosive factories in order to find out the latest methods in use in the manufacture and handling of explosives, as well as to ascertain the different materials that enter into them. So that in all these ways the engineering colleges are trying to give their students some information which will be especially useful to them in the army if they are drafted, or if they become officers in the army.

There is still another important question before the engineering colleges: If they lose all of their men over twenty-one years of age, except the physically unfit, and have left, therefore, only the freshmen and sophomores, the greater part of whom are under twenty-one years of age, is it necessary for them to change, or is it not advisable for them to change, their courses of study in order to fit these men for the actual things they may have to do after they go into the army? It has seemed to some of us as though we ought to do this; that is to say, that if we know our courses in the engineering colleges are to be limited to two years, we ought to materially change our courses of study during those two years in order to fit the men for some of the engineering work which it would be possible for them to do.

In conclusion, I would say that the engineering colleges have tried to look at this matter in an entirely unselfish way. They are not thinking of the number of students they will have, or of any income which will come from these students, but only of the question of the most efficient way in which they can train these young fellows for service, and they are ready to do anything which the Government wishes them to do in order to carry out this plan.

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No. 1602 *d*

THE OPPORTUNITY FOR INDUSTRIAL RESEARCH

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Non-Member

THE successes of the past and the host of problems awaiting future solution should be ample proof that industrial research has before it a field of unlimited opportunity. There are many phases of the subject which might be discussed to advantage at this time, such as the extent to which industry should carry on pure scientific research, the extent to which different industries could pool their research interests, methods of attacking research problems, the education of research workers, the coördination of industrial, governmental and university research, and others. This paper will, however, be confined mainly to an attempt to show by illustration some of the opportunities which exist. Possibly no better example could be chosen than that of the study of alloys, and this should appeal to the mechanical engineer as no other single development has perhaps contributed so much to his progress in the last two decades. Machine tools have been revolutionized. There are few important machines today which do not depend on alloys for some of their vital parts. The automobile, the airplane, the modern locomotive, dynamo-electric machinery, and many others, would require changes much to their detriment if modern alloys were not available.

And yet, in spite of the work already done on alloys, we have explored but a fraction of the really useful fields. Few, if any, general surveys have been made of the possibilities of binary and ternary combinations, and such studies should yield results of great value. The subject might be attacked in either of two ways: first, by endeavoring to get at the fundamental laws governing the alloy-

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ing of metals so that the results of making any particular combination could be predicted; or, second, by experimental methods, actually making and testing a sufficient number of the alloys under consideration to give the data essential. The purpose of such a study may be to produce an alloy with certain desired characteristics for a specific purpose, or it may be to determine the useful alloys possible from the combination of any two or more metals. The former may be relatively easy or very difficult, depending upon the requirements. The latter cannot fail to be anything but difficult and long-drawn-out, no matter what the method of attack. Let us consider briefly what such a survey means. It would be desirable to start with chemically pure metals, but metals chemically pure are practically unknown and often metals of a purity not at present commercially obtainable show characteristics very different from those commercially obtainable. For example, magnesium as ordinarily obtained is quite brittle, while the metal approaching chemical purity is very ductile. Tin of high grade combined with lead gives us a solder with well-known characteristics, while certain commercial tins now on the market carrying small percentages of bismuth impart to solder characteristics markedly different from the purer tin. Consequently natural impurities must be studied both as to their influence and as to their elimination. Methods for the preparation of the constituent metals with unusual purity must be developed. The differences between the effect of natural impurities and added impurities must also be examined, as these differences are sometimes very marked; as in the well-known effect of added sulphur as compared to natural sulphur in steel for certain purposes.

Keeping in mind the necessity for pure materials and the influence of impurities and alloying methods, we may assume that a series of alloys of any two metals is to be made varying in their proportions by 1 per cent. This would give us ninety-nine different alloys for each grade of each of these two metals. Each of these will require a large number of tests and repetitions to determine the various influences which may change their important characteristics, and each sample will require a large number of determinations to arrive at its chemical, physical, electrical, magnetic, thermoelectric and other characteristics. It may be necessary to study the effect of each natural impurity on each alloy of the series, which will multiply the tests manyfold. Those which promise to be commercial will require many further tests to deter-

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mine their working qualities and adaptability to commercial uses. In addition to the above, it is well known that certain alloys have very sharp and very marked inflections in certain of their characteristic curves, sometimes within a range of less than 1 per cent variation in their composition; as, for example, the variation in the thermoelectric value of certain nickel-iron alloys which occurs at approximately 27 per cent nickel.

Such a study even of a single series of binary alloys would involve tens of thousands of determinations and much time and expense. If we add a third and a fourth alloying metal, it will readily be seen that a lifetime would be entirely too short to compass a full exploration of such a series. In fact, it is doubtful whether a relatively complete study of the possibilities of a single binary combination could be accomplished by any one in an ordinary lifetime. A very elaborate study of the single alloy, 88 per cent copper, 10 per cent tin and 2 per cent zinc, has been under way for two or three years, the leader in this work being the Bureau of Standards, assisted by a number of producers and users of this material. The Bureau has outlined over a score of characteristics to be determined and the work is as yet far from complete.

It may be argued that such an elaborate study would not be warranted even to give complete data, as many zones could be passed by as not promising or a few experiments at most prove that the combinations in certain zones were of little or no commercial value, but we are learning that where ordinary methods with metals of commercial purity fail to give useful results, other methods with purer materials may give results of great value. Unfortunately, we do not know the theory of alloying well enough to predict results with any certainty. We know of no theory to account for the fact that an alloy of 3½ per cent nickel with iron has low permeability at low inductions and high permeability at high inductions, while an alloy of 33 per cent nickel with iron has high permeability at low inductions and low permeability at high inductions, and an alloy of 27 per cent nickel with iron is totally non-magnetic, except at very low temperatures. Or again, how shall we account for the fact that certain alloys of copper, aluminum and manganese, where all the constituents are non-magnetic, produce an alloy which is strongly magnetic, while an alloy of 12 per cent manganese with iron — the latter being our most strongly magnetic material — gives an alloy which is non-magnetic. Again, alloys of aluminum and tin, with or without other alloying metals, may make

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alloys with fine characteristics when first smelted, only to disintegrate to powder later. No satisfactory explanation for this action is now available. These phenomena are just as difficult to explain as the fact that two gases, hydrogen and oxygen, combined in a certain proportion give a liquid (water), while three materials, carbon, hydrogen and oxygen — the one a solid, the others gases — when combined in certain proportions give a resulting gas, in other proportions a liquid, and in still others a solid. The idiosyncrasies of certain alloys cited above show the futility of attempting to predict results with our present theoretical knowledge of the subject. It is probable that the necessary theory for a full understanding of the subject may come only from a study of the atom — its structure, its combination into molecules and the ultimate forms and characteristics which the constituent elements may take. A general solution will hardly be possible from a study of the chemistry or the metallurgy of the subject, but by a coördination of the chemistry, the metallurgy, the physics and the magnetics through the work of the molecular physicist. Thus the ultimate solution of a very practical industrial problem can hardly be expected except through the work of the pure scientist. True, the patient experimenter trying to explore the whole field may furnish the facts to prove the theory conceived by some brilliant mind, which will make further drudgery in this line largely unnecessary.

The above example has been dwelt upon at some length to show the possibilities of unlimited research in what might seem from a superficial examination to be a highly restricted field. This is equally true in numbers of other fields. We know very little of the laws governing insulation and the theory of conduction in dielectrics. It is possible that the fundamental laws governing the characteristics of alloys may also explain some of the mysteries of dielectrics.

The examples cited illustrate another phase of the subject that may be emphasized to advantage, and that is the ever-widening field of any research, no matter how restricted in scope its object may be. The study of a single series of binary alloys may necessitate studies in the source and preparation of the raw materials, methods of smelting and alloying, a study of containers and molds for the molten metal, types of furnaces, temperature-measuring devices, smelting and pouring temperatures, rates of cooling, effect of quenching, methods of forging, rolling and drawing, development of new test methods to determine new characteristics, and many

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other phases of the subject. Totally new characteristics may be found by using hitherto untried methods; for example, alloying under extreme pressure or temperature, or both. If the worker is to understand fundamental laws governing the work which he is undertaking he must have a thorough knowledge of the chemistry, physics, mechanics and magnetics of the subject, or he must have co-workers available who can look after such phases, together with the necessary equipment for carrying on the necessary tests.

THE NATION COMPARED TO AN ALLOY

If this country is the melting pot, then this nation is an alloy, an alloy infinitely more complicated than any I have described. What are the influences for good? what are the poisons? what evil influences can be fluxed off in the smelting? what will remain to vitiate the resultant alloy? what will be the result of the heat treatment of war? will it respond to the new treatment necessary after the war? What a research we have before us as engineers and citizens!

No paper on research today is quite complete without some reference to the war. Prior to the war some one decried research and scientific development generally, because of the possibility of their making war more horrible when war should come, and many felt that war would become so horrible as to be impossible. We must admit that much of the horror of the present world war which particularly appeals to our imagination has been made possible through our latter-day research and scientific development. We have but to refer to the submarine, the airship, noxious gases and high explosives to illustrate the point. It is doubtful, however, if any right-minded man would wish that all development through research should have been halted at any previous specified time, in order that the use of such things should be impossible. We would not give up our advances in chemistry in order that high explosives and noxious gases could not be used. We would not discard the telephone in order that the submarine could not be provided with listening ears. We would not discard our advantages in aeronautics in order to prevent the dropping of bombs on defenseless women and children. Each element of frightfulness based on scientific research can and must be met and conquered by scientific research. The agents of frightfulness and the means of overcoming them will become the means of restoration and reconstruction after the war. The "die is cast" and we must go forward with our

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research as never before, both to win the war and to provide for the readjustment necessary after the war. We are spending our natural resources at an appalling rate, but we must use the last pound of coal and the last drop of gasoline, if necessary, to win the war. If this be necessary, we must find other substitutes through research. The development and use of the internal-combustion engine has reached a stage which makes it impossible to think of the world after the war without internal-combustion engines, even though our present fuel for them be exhausted. Furthermore, the restrictions imposed by the war have taught us that many substitutes are possible where such substitutes would have been considered impossible or at least very undesirable before the war. Tin-base bearing metals were considered absolutely necessary for some services until the scarcity of tin made it necessary to use a substitute containing little or no tin, and this has been perfected until it meets every service equally as well as the genuine babbitt.

RESEARCH NECESSARY TO WIN THE WAR

We cannot emphasize too strongly the two main points brought forward in this paper: first, the unlimited field open to research in every conceivable line of endeavor, and, second, the necessity of taking advantage of these fields both to win the war and to provide for the reconstruction and readjustment that must follow. Research can and must do its bit now. Research can and must be an important factor later. To meet these requirements we need workers trained in the fundamentals of all branches of science who can bring to their work the devotion, the enthusiasm, the optimism and the imagination so essential to success in any work and doubly so in research. We need the aid of all who can help in the training of research men. We especially need the aid of men with imagination who are in a position to furnish the funds, the equipment and the organization to provide that pure science and applied science shall advance in every possible way. It is not hard to show that industrial research through applied science pays. It should not be difficult to show that this depends on pure science and, therefore, that pure science should pay in every sense of the word.

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No. 1602e

THE AGRICULTURAL PROBLEM

By Liberty H. Bailey,[1] Ithaca, N. Y.
Non-Member

JUST now we hear much about the farmer's attitude toward the great affairs confronting us. There is considerable criticism. All the criticisms I have heard are projected from the point of view either of class organization or industrial organization. Those who would defend the farmer speak of his psychology and the necessity that the rest of us understand it. The result is that much of the treatment of the farmer is cajolery. The situation lies far deeper than psychology. Let me give you a formula:

> The farmer is part of his environment, matching himself into his background, perhaps unconsciously, much as a bird is matched, or a tree, or a quadruped. His plan of operation, his farm management, is an expression of his situation in nature: he has worked it out because it fits. He cannot shift it radically to meet the advice of any other person. As he himself develops in ability he will modify his plan of operation so far as he can, but the plan must always fit his place in the environment; no great change is possible unless his natural conditions change: he does not make his conditions. The farmer exemplifies, in the human range, what the naturalist knows as "adaptation." His situation does not admit of compromises, perhaps not even of adjustment, and therefore it may not be understood by teachers, publicists, officials.

THE FARMER CANNOT BE PRESSED

The consequences of this formula, if it is true, are tremendous. All the advice given the farmer that does not recognize his neces-

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sary adaptation to his environment is useless; and useless advice is harmful. It is of no advantage to rail against the farmer any more than against the wind or the rain. It is idle to try to apply to him the pressures that are exerted on corporate business. It is of small consequence either to praise him or to condemn, to take sides for him or against him, except in so far as it may affect his spirit as a man. When, under pressure of great crises, we radically change the conditions under which the farmer works, we must allow him time to readjust himself: he must take account of the latitude that he may reasonably expect in weather and soil and human forces. He needs not favors, but conditions that will allow him to operate. The natural conditions within which he works cannot be changed, but they can be modified in some ways, and he can make new adjustments, within certain limits; these possibilities he begins to understand, and they are parts of his problem as a farmer; when the economic or outside conditions are changed, the modifications must be such as will match the natural limitations, if he is expected to adopt them. In the present crisis our public agencies must understand and recognize what can reasonably be required of the farmer.

It is an old adage that appearances are deceitful. I wish to add that they may be misleading. Persons managing corporate, industrial, labor and professional affairs have a certain air and habit of presentation. The farmer operating his farm may not have this air. He has nothing to present. He may be following a plow in the back lot, unshaven, trousers in his boots, working until the work is done, even though the clock points to five. Perhaps he would not discuss politics or civics or religion, at least not till he knew you; but, good or bad, he has worked out the management of his farm, and he thinks he knows why. He will listen to your advice; then he will go on with his plowing. He is hard against facts — real facts, not paper facts; he accepts them and acts accordingly. You may not like him, but he himself is a fact.

POPULAR ATTITUDES TOWARD FARMER RIDICULOUS

Bearing in mind these fundamental considerations, established in the nature of things, some of the popular attitudes toward the farmer become ridiculous. I was out of the country when war was proclaimed, but I understand that everybody who had a public voice fell to advising the farmer. This is futile, since the farmer is the one part in the population to whom advice of this nature is of

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no value, and for the reason that it cannot be applied. I am sure that much of this advice made no account of situations that neither the farmer nor any one else can change. Such advice is not only vain, but it works mischief. The farmer fails to accept the advice not because he is unwilling, but because he cannot. It is suggestive that every person thinks he can advise the farmer in his occupation; it is significant that the farmer does not undertake to advise other occupations and professions.

It is simple enough to change an outside or commercial condition in relation to the farming occupation; it is quite another matter to expect the farmer to accept it unless other essential conditions are changed to meet it. Fixing the price of any product, while it may be necessary in times of crises, does not add fertility to the land, or modify the weather, or affect the habits of a sheep or a horse or the requirements of a herd of swine. To say that a billion dollars is to be added to the income of farmers by war prices means nothing, unless we have at the same time a statement of outgo. To say that the increased gross value of farm products of 1917 over 1914 represents war profits is to state only one factor in a transaction, and to state it loosely. To advise the use of less milk in order to save it does not take the cow into consideration; the cow is not a machine that can be stopped by turning off the steam and discharging the operator.

To establish any regulation touching production on a basis of compromise or agreement between contending parties does not take into consideration the fundamental problems on which the regulation must rest for its operation. This is well expressed in Warren's recent statement following a long hearing on the cost of milk, that there is no known way of making a cow produce milk by argument.

The political method, which is the method of compromise or expediency, cannot change a single fundamental fact in agriculture.

IS THE FARMER PROFITEERING?

You understand that I am not defending the farmer — his acts are as much open to review as those of any other citizen — I am merely stating his natural situation. As illustration, let me refer to the recent charge that he is profiteering. The farmer does not make profit in the commercial sense, but only a labor income. Now and then a farmer may buy and sell without producing, or even speculate, but this is not farming. The producing farmer does not become "rich" in the commercial sense. His occupation yields only

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the returns from his work. His overplus is likely to go back into the land, and the next generation has the benefit.

One of the most amusing statements I have heard is that reported of an influential financier to the effect that we must now take the farmer in hand and control him. The idea is that the farmer is becoming too powerful and makes too many demands. Now, for the past ten years or more public men have been advising the farmers to organize for protection, and the farming people have been shown the results that have been won by organized labor and industry; yet as soon as the farmer begins to use this dangerous weapon, a shout of alarm goes up from those who have advised it. If the farmer anywhere uses the weapon of organization, he only follows the precedent of industry and commerce. This is to say that the weapons of industry and commerce are then turned against themselves. The present mood to discipline the farmer is but another expression of the old disposition — so old as to be automatic — that the farmer must be kept where he belongs.

AGRICULTURE VERY LITTLE ORGANIZED

In fact, however, agriculture is yet very little organized commercially or politically. Former attempts have failed. We are watching the two movements now before us with new interest; it is yet too early to measure their accomplishments. It is now charged that farmers are withholding the sowing of wheat in order to hold up the prices. In the first place, there is no organization of farmers that can control the wheat situation; and if any number of individuals reduced their own production they would be playing into the hands of the heavier producers or of handlers. It is impossible for farmers to control their production as manufacturers control their output. Whether a man sows more or fewer acres of wheat, he does not know what his crop will be: the unpredictable conditions that make the wheat crop are too many.

Organization for commercial offense, or even for defense, is indeed a dangerous weapon. It is dangerous in itself; it is dangerous because it forces government into compromises, and also because it relieves government of its plain obligations; it is dangerous because it sets one part of society against another. In agriculture it is specially dangerous: it has here all the danger that it has in any other realm, and, besides, it cannot change a single natural condition.

[Having laid down these general statements, the speaker illustrated by calling attention to advice that is likely to be given the

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farmer and which cannot be applied because it does not fit. He spoke about plans for doubling the produce of the poultry yards and other stock, bringing out the fact that this requires more feed, and that this feed cannot be fed to livestock and to humans and certain parts of it sent to the Allies at the same time. To talk about doubling the output easily in poultry or some other special line under the limitations and conditions that are now apparent may be little more than nonsense. He also spoke of the fallacy of trying to secure more beef by allowing the veals to grow up. Veal is practically a product of the dairy regions, and the only reason for desiring calves is that the cows may freshen. If these calves are all kept for beef, then they will compete with the cows for feed and labor and the dairy business will greatly suffer. Recent studies have shown that possibly one way to increase the supply of meat is to kill the veals earlier rather than later, so far as it can be done within the law. — EDITOR.]

FOOD AND THE LABOR PROBLEM

The food problem is now on us with staggering force. Fighting men, munitions and similar supplies, and food are the fundamental or essential materials in the prosecution of the war. We now face the problem of supporting vast armies in a foreign land, making good the losses by land and by sea, and supplying the needs of millions of allied and neutral peoples. We are to expect that the problem will increase in magnitude. Never has a people been presented with a food problem of such stupendous proportions.

At the outset we are to face the contingency of the probability of a lessened yield. In the three war years the yields of the staple grains have been heavy. Only five times previously in the last twenty years have they been as great. This fluctuation is due, to a great extent, to unpredictable conditions of weather and climate. In two of the years the yields have been very low, and if very untoward conditions should arise next year, it is well within the range of possibilities that disastrously low yields might result, although they are not expected. We must take every precaution, therefore, to reduce all the elements of chance that are reducible in order to safeguard the situation and to secure a food supply as nearly adequate to the situation as possible. We are already applying these cautions effectively.

The labor condition may prove to be the key to the problem. Farm laborers and farm operators both are involved. They have

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volunteered; they have been drawn off by the great industrial demands, receiving wages that food production cannot pay; they have been drafted. The situation is not to be met by argument or by any array of tabulated figures. The actual experience of the farming people the country over must be accepted as true. The farmers also must coöperate to the full.

Farmers should not be exempted as farmers, for exemption is not a class interest. Yet we must save the energies of the people for the production of food as well as for other war purposes. Some of the harvest of food may be accomplished by volunteers, young and old, sent to the rural districts when emergencies arise; this, however, affords no solution of the regular and steady application that is needed on the land, a need that is now greatly increased. The producing of food, as the producing of anything else, needs dependable and experienced labor; food production needs farm labor rather than city labor.

FOUR REQUISITE FOOD REGULATIONS

The food production is not to be maintained by the ordinary processes of economic regulation, particularly when the law of supply and demand is so much interfered with or even abrogated. Many movements and activities will influence the production, but four are of paramount importance.

1 We must save the food. This saving is not only economizing in the use of it, whereby we reduce the waste, but quite as much in the direction of the diet and the reconsideration of the family activities. Fundamental changes are to take place herein if the war continues any length of time. To every person in the land, to every family, to every hotel and club, to every social organization, the call must come to consider whether the present eating habits are either sound in themselves or patriotic. Not only does the question of wheatless and beefless days seem to be involved, but that of better dietetics as well.

2 We must save labor. Extensive activities employing labor, perhaps whole industries, must be stayed; perhaps some of them should never be revived. If we eliminate the useless and also the unessential, we shall be able to release much labor. The simplifying of the household scheme will also liberate woman labor for industries and farms; we shall need it all. If the war long continues women must take the places of men in countless industries where heretofore only men have been employed.

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3 We must grow more food on the small home properties in city and town and suburb. This is not farming, for the householder does not maintain himself and family by the raising of supplies. This activity is justifiable only so far as the operator does not demand labor that can be used elsewhere. Himself and members of his family and household establishment should do the work. There may be many failures and disappointments; but there is no charge for labor. What energy one puts into the raising of food is likely to be deflected from less patriotic uses. Much foolishness is displayed in some of these home food gardens and in some of the semi-public enterprises of this kind. I hope that something has been learned this year. We may expect better results next year, even if the gardens should be fewer. We shall learn to grow the dependable things, few in number, and those that can be utilized to best advantage in the family. Great secondary and civic gains will result from this tilling of the land by the sweat of the face. Yet, with all that can be accomplished in the making of home gardens, we shall not affect the production of the great staples, as the breadstuffs and the red meats; but we may relieve ourselves of the necessity of using so heavily of these staples, thereby saving them for export.

4 We must directly increase production on farms. To this end we must establish food production on a wartime basis, giving it the best economic protection and the directest aids. Here lies the great remedy. The major strategy of the nation having been determined, we must then apportion and distribute the activities of the people toward the accomplishment of the one result. No industries or activities should be allowed to proceed at the expense of munition making and food production, or with the distribution of them, or any part to work to the disadvantage of another part: all the parts make the whole. The entire people now makes war. The war is one problem. If by stimulation, oversight and regulation the food situation cannot be met, then men must be assigned to farms as definitely as they are assigned to armies.

North America is the last defense in the food support of the war.

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No. 1602*f*

THE FUEL PROBLEM

By L. P. Breckenridge, New Haven, Conn.
Member of the Society

PRECISELY stated, the fuel problem is that the coal bin of the United States is not full. How much do we need to fill it? One hundred million tons. Can we get it? We will try to produce more coal. We may produce fifty million more than we have ever produced, but we shall have to save another fifty million.

If you will build a coal bin 1000 feet on each side, that coal bin will have to be 4½ miles high to hold the coal which must be mined this year in the United States. That is a good-sized coal bin, higher than any mountain in the United States, and it takes a good deal to fill it, but if everybody saves a little coal we will save fifty million tons.

The question of the fuel problem is divided into three parts: the production of coal, the distribution of coal, and the use of coal.

In connection with the subject of production, Dr. Noyes, of the Fuel Administration Department, says that there is no use of producing coal — taking it out of the mines and piling it around the mouth of the mine. It is better to go down into the mine and get it with the machinery available than to raise it when there are no cars to put it in. If that is so, and it seems entirely probable, the coal in the mine is ready to be taken out and is being taken out as fast as cars are put there to receive it.

The railroads of this country distribute a large proportion of our coal, about 85 per cent, and nearly 35 per cent of the entire freight they haul is coal. No wonder we would like to fill the coal bin just to have the coal, but we would like also to get rid of the job of hauling it. We need the railroads for other things, not only for hauling food, but for materials which go into munitions. The problem of distribution is after all one of the most serious problems in connection with the fuel problem at this moment.

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The problem of the use of coal divides itself very naturally into two parts: First, if we are to use coal we should use it with economy; second, will the time come when it will be necessary to limit the supply of coal to certain industries? If we are careful of the

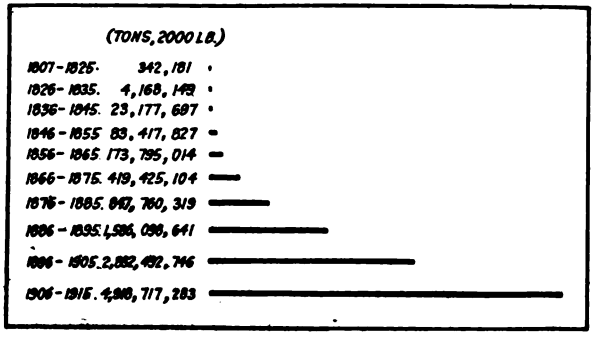

FIG. 1 TOTAL ANTHRACITE AND BITUMINOUS COAL PRODUCTION IN THE U. S.

coal we possess that will not be necessary; but if we are not, there will have to be some priority of use of coal.

It is preëminently the function of the engineer to use coal with economy. During the entire period of this Society's existence, 38

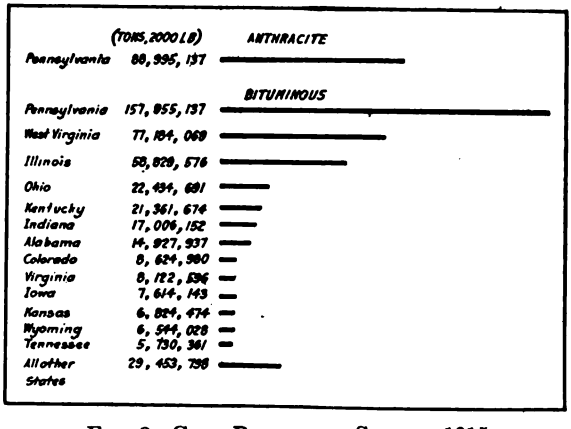

FIG. 2 COAL-PRODUCING STATES, 1915

years, I doubt if there has been a meeting when papers were not presented which referred to the economical burning of coal, or the economical use of steam, or the economical use of electricity. They are one and the same thing, as we burn coal to make steam, to make

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power, or, as a secondary product, the electrical energy which is to be distributed for power and lighting uses.

Sixty-seven per cent of all the coal produced is used to make steam. The steam is not all for power purposes, however, part of

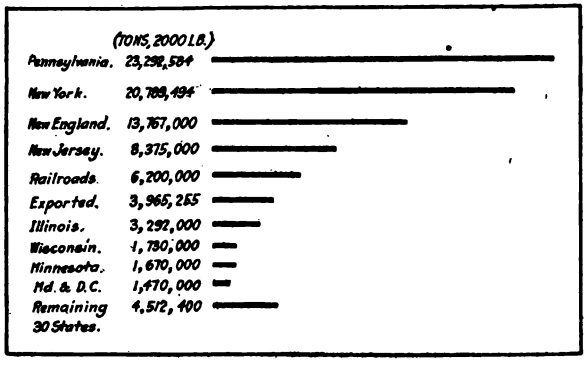

FIG. 3 STATES USING ANTHRACITE COAL, 1915

it going for heating. But this use of 67 per cent of the coal production shows the desirableness of using economy, and saving a lot of this coal by saving steam, and by saving the power we make from steam.

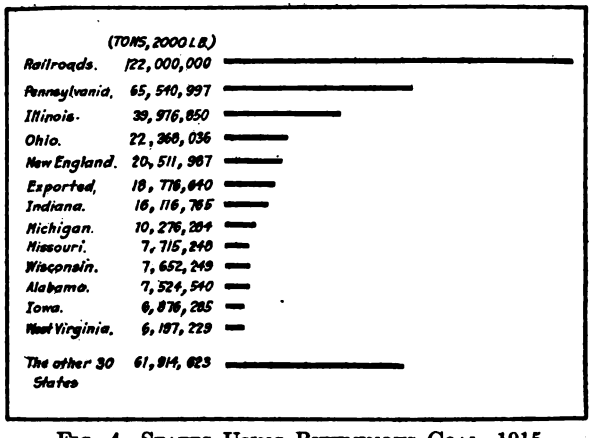

FIG. 4 STATES USING BITUMINOUS COAL, 1915

The United States, Great Britain and Germany produce the coal of the world, the world's production now reaching about 1,600,000,000 tons.

In the United States we mine, speaking broadly, two kinds of

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coal, anthracite and bituminous. All of our anthracite coal comes from Pennsylvania, from Scranton, Wilkes-Barre and vicinity, and we have never yet produced 100,000,000 tons a year. In the rest of the country we get bituminous coal, which varies much in its composition. We get most of it from Pennsylvania and West Virginia, a lot from Illinois, and a little from the lignite fields west of the Mississippi. We are producing bituminous coal in increasing amounts, and will mine close to 600,000,000 tons this year.

Anthracite coal becomes more valuable in the ground next year, and we have only enough to last perhaps one hundred years. Our bituminous coal will last us 1500 years, according to Geological Survey estimates.

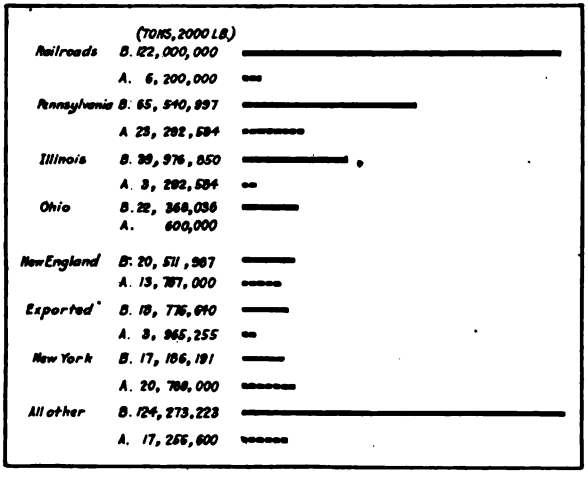

FIG. 5 BITUMINOUS AND ANTHRACITE CONSUMPTION, 1915

Fig. 1 shows the coal production at each ten-year interval in the United States, beginning in 1800. Up to 1885, about the time this Society was formed, we had not mined in this country as much as was our increased production in the last ten years.

Fig. 2 shows the states which produce coal, Fig. 3 those which use anthracite, and Fig. 4 those using bituminous. This year I think the railroads alone are using 145,000,000 tons, and will need, and must have, perhaps, more.

Fig. 5 shows the proportions of bituminous and anthracite coal used by the various states. The railroads only use a very little anthracite compared with bituminous. Illinois uses only a small amount of anthracite. Ohio uses a very small amount of anthra-

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cite, less than the city of New Haven. New England uses more bituminous than anthracite.

Fig. 6 shows the coal consumption by industries. Fig. 7 shows the per capita consumption in various sections of the country. In

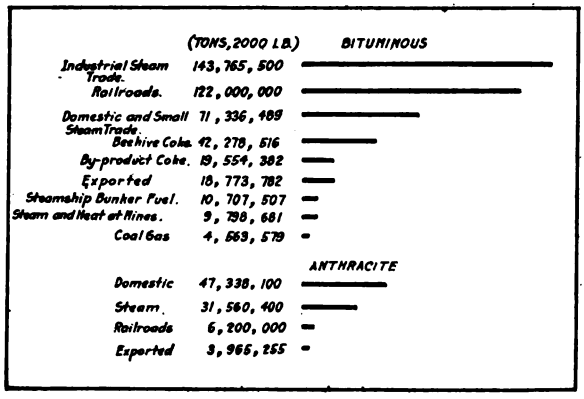

FIG. 6 COAL CONSUMPTION IN U. S. BY INDUSTRIES, 1915

the Pacific Coast states the consumption is only about one-third of a ton per capita — they use hydroelectric power and burn oil in their steam power plants, and as the winters are mild they do not use much for the purpose of keeping warm.

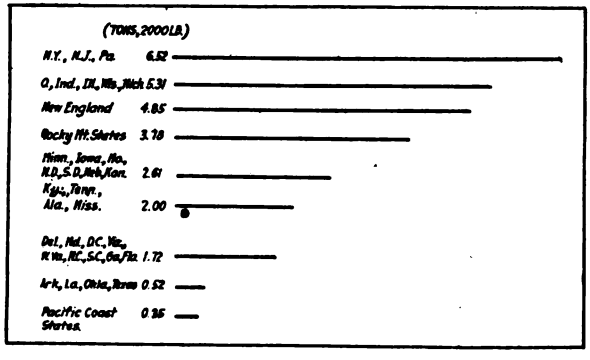

FIG. 7 PER CAPITA COAL CONSUMPTION IN U. S., 1915

The Fuel Administration has a coal-conservation department, in charge of Dr. Noyes, and his activities reach to every state where there is a fuel administrator. The Bureau of Mines, augmented by a committee appointed by the four national engineering societies,

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is acting as technical adviser to this conservation department. The various engineering societies can give much help to this question of conservation in their own localities, and it would seem they should coöperate with the fuel administrator in their particular locality.

The United States Chamber of Commerce, having connections with 950 cities in America, is issuing from time to time valuable information bearing on this subject, and its committee on coal conservation has invited Dr. Hollis to appoint a number of engineers to sit with them; and so they are helping in that way. In many of the state fuel administration offices we have engineers working with them to help save coal.

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No. 1602*g*

MOTOR-TRUCK TRANSPORTATION

By William P. Kennedy, New York, N. Y.
Member of the Society

MOTOR-TRUCK transportation has now become firmly established in military and commercial service, and the purpose of this paper is to point out the developments to be expected from our immediate necessities created by the existing condition of war.

There are three stages to the introduction and development of most of our industrial utilities: first, the pioneer stage in which the designer and producer bring the apparatus in question to a condition where it can be practically employed as an economic device; in this stage there is a period during which considerable missionary work must be done to induce the prospective user to recognize its economic advantages. The next or second stage is that in which the apparatus is used in a preliminary way, during which period the user becomes gradually familiar with the possible accomplishments of the device and begins to have confidence in its commercial value, by being able to satisfy himself definitely of the reduced expense or increased performance which he is actually gaining by its employment. The third and last stage is that in which the device becomes a competitive necessity in the hands of the user, due to its general employment in commercial service. In rare instances the coming of this stage may be hastened by some extraordinary situation in which the failure of existing means for performing equivalent service forces the employment of the new device as a necessary substitute.

In the development of the use of motor-truck transportation we have now reached the beginning of the third stage, just described, and are confronted with a situation where the older means of transportation is so overcrowded and congested as to demand the immediate and general use of the motor truck as an urgent expedient for relief. Our general situation therefore at the present time of congested rail and water transportation may be the greatest possible

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boom that could exist for a very extensive development of highway transportation, by means of the motor truck. This development during the next year or two will probably be the equivalent of that which would gradually take place over a period of twenty-five years under normal circumstances.

As indicated above, the reliability and economic value of the motor truck is already established. The employment of these machines to the number of 300,000 throughout the country in commercial service is sufficient proof of this. In its application to military requirements there has been a more rapid and conspicuously successful development, as is evident by their numbers and the character of their service in the various zones of military activity in Europe, as well as the great quantity employed for military requirements at the home base of each of the belligerent nations.

While the motor truck cannot be regarded as having created any revolutionary change in methods of warfare, the effective character of its service, wherever time has been an important element, has had a marked influence in speeding up military operations. It has consequently found its place as an indispensable adjunct in military equipment, from which it can never be displaced and in which its usefulness will continue to extend. The motor truck has provided the army with other utilities beyond road transportation of munitions and supplies, in furnishing the speedy ambulance, the scouting armored car, the mobile gun, the powerful caterpillar tractor, and finally the tank as a formidable fighting machine.

There may be lines of demarcation as to the limitations of the motor truck in military field service between the railroad in the rear and the army mule at the front, but its permanency and usefulness in between these limits is unquestioned. The extension of its application in overlapping the service of the railroad and superseding the army mule has been demonstrated on many occasions of emergency, and it is therefore likely to continue forcing its value in both directions as its superiority becomes more frequently demonstrated in cases of actual necessity.

The motor truck is already so well entrenched in military service that our Government has been abundantly supplying itself with many thousands of these machines. It has been able to take advantage of the experience of other nations engaged for a longer period in the conflict to furnish itself with the most suitable equipment which the industry could provide as its regular commercial products. It has gone a step further in securing through the col-

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lective coöperation of the engineering ability of the industry several special types of motor trucks, the design of which is based upon the accumulated experience of three years of vigorous warfare; while the industry in the few years of its rapid growth has become so substantial that the emergency requirements of 30,000 to 50,000 motor trucks can be furnished almost as a matter of course, and without any serious impediment to the routine conduct of its business.

Our immediate interest is now concentrated not upon these past accomplishments, but in a determination of what are to be the demands of the near future in furnishing domestic highway transportation to aid in conveying, from our scattered centers of production to our seaport terminals, the vast quantities of supplies and munitions required to maintain from one million to five million men in the field in a foreign country.

We have already in evidence the limitations of our old-line means of rail and water transportation, and although vigorous steps are being taken to find satisfactory remedies for their congested condition, the problem of making these already overworked facilities conform to our increasing necessities is an extremely difficult and complicated one. The situation calls for extraordinary activity and extraordinary methods in finding its solution, and one of the principal factors which will develop as an element in the solution of this great problem will be the employment of motor-truck trains in scheduled operation over our principal highways.

The producer, merchant and consumer of materials requiring transportation from one place to another throughout the country have become so habitually shackled to the limitations of our railway and waterway transportation facilities that it is extremely difficult for the prosaic commercial mind to release itself from its accustomed methods and to rise up and find a new and efficient means of relief. It will probably require the superior genius of the military mind in its capacity for meeting emergencies, coupled with the resources which military organization provides, to take preliminary and effective steps toward making use of the motor truck and the highway to offset the limitations imposed by our older transportation systems.

Fortunately, the situation has all the elements which can possibly contribute to success practically lying at hand waiting to be utilized; and the only thing remaining to accomplish the purpose required is the necessary authority with a competent executive or administrative organization to put into actual operation road motor

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trains adjacent to all the centers where freight congestion now exists.

The ability of the motor truck as an individual operating unit or as a tractor coupled to trailer equipment has been well demonstrated under a great variety of operating difficulties throughout the country. All the highways in the country may not be fit for transportation of this kind, but over the comparatively limited number of routes where the operation of such motor trains would be required the conditioning of highways is either an accomplished fact at present or could be made so with little difficulty or loss of time, by making use of the facilities which most of the state highway organizations have at their command and are ready to supply for such emergency requirements almost immediately upon notice to do so.

In the present-day motor truck, backed by the brains and facilities of one of the greatest industries ever developed, we have the means for providing transportation equipment with which we can accomplish extraordinary service. For several years past the manufacturers of motor trucks, under the stress of keen business competition among themselves, have developed the machines produced to a point where they are capable of performing almost any task allotted to them. Aside from their normal functions of transporting freight, they are in many instances called upon to perform a great variety of military service incidental to transportation. In some cases their equipments constitute portable power plants for performing service of some distinct character, such as that required in logging and mining camps. They occasionally furnish lighting. Frequently they perform loading and unloading operations, such as the hoisting and dumping of coal bodies, or the removal and replacement of separate bodies which have been loaded while the truck itself has been absent on its delivery route. In fire-fighting service they are practically replacing the old line of equipment, and a special type of motor truck has been developed which is now regularly known as a road builder, hundreds of which are doing marvelous work in the rapid development of our highways.

It will therefore be seen that under the intensive development of competitive motor-truck equipment the manufacturers have been prepared for just such emergency requirements as they are now likely to be called upon to meet, and therefore any organization which may be developed, either by the Government or by commercial institutions, to solve this problem of highway transportation

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will find the truck manufacturers perfectly competent to furnish quickly suitable machines in any capacity or number that may be required.

With this assurance as to an adequate supply of rolling stock, the next step in the project will be to put a few selected stretches of highway into serviceable condition and to keep them so.

Whenever the question of highway transportation has been considered in the past, the good-roads topic has always been introduced and discussed in terms which embrace the entire road system of the country, and the magnitude of the task of putting this complete system into first-class shape is usually dwelt upon as an almost insuperable accomplishment. It requires, however, no very great analysis to bring out the fact that only a very small fraction of one per cent of the highways of the country would be required for the contemplated service of relieving our present congestion or expediting the movement of freight between the principal centers of production and our seaports. This being so, the facilities now available in each state for the construction and maintenance of its roadways, if concentrated intensively upon the few routes likely to be required for this character of service, could put them in excellent condition and keep them so with comparatively little effort and expense. Consequently, this project of bringing into existence organized highway transportation has none of the cumbersome impediments usually attendant upon railroad extension.

Many cases already exist where limited highway transportation is operated on schedule over definite routes. Many more systems would come into existence rapidly by virtue of their commercial value were it not for the fact that it is difficult to procure capital in large quantity for this kind of investment. One of the alleged reasons for this difficulty is the fact that the power of railroads has in the past been used to obstruct parallel competition of any kind, and this promotes the belief that if road-transportation operations were organized on a large scale the same influence would be felt in interfering with their development and prosperity. If this is really the case, then it will require initial steps on the part of the Government in such an emergency as the present one to put into extensive operation road motor-transport service, and incidentally prove its practicability and establish the permanency of such methods. Action of this kind should be advocated and strongly urged for the many advantages which would result from the spread of the use of this highway motor transportation. Its competitive influence would

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be a very valuable one to the public, as placing in the hands of producers and merchants their own independent facilities for limited freight movement would bring about marked economic changes in which all would be likely to benefit.

We should not be slow to take advantage of the lessons which have been taught us in this direction by France, England and Italy, in carrying into effect, almost immediately upon the opening of hostilities, road motor transportation upon an extended scale. Some cities and many of the small towns in these countries are almost entirely dependent upon the motor truck as a means of conveyance, and the well-defined organization which has been brought into existence to maintain the equipments employed and to keep in condition the road surface required, are examples that should exercise a stimulating influence upon us to make advanced preparation towards meeting the more serious conditions which the increasing demand for transportation is likely to force upon us.

DISCUSSION

GEORGE P. HEMPSTREET said that he wished to call attention for a moment to a peculiar state of affairs. We had one branch of the Government anxious to promote motor transportation, and had been assured that there was an ample supply of rolling stock available. In order to use that rolling stock it was necessary to have a highway to run it upon, the first requisite of which was a sufficient foundation, generally of crushed stone or gravel.

Another department of the Government had issued Priority Order No. 2, which prohibited the shipment of gravel or crushed stone or anything to be used for road construction in open-top cars. Most of the quarries from which crushed stone was taken could only put their materials into open-top cars, as it was very difficult and expensive to use any other type of car, and very difficult to unload it.

The question might be asked, Why not use motor trucks? A motor truck could be used to haul a load of five tons, and if the load was worth $1000 the $25 charge for hauling would not be very excessive. But if the load was only worth $2.50, a freight bill of $25 would be excessive and prohibitive.

So we had one department of the Government which wished to have motor transportation and to use good roads, and another which was preventing their construction.

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There had been every effort made to relieve freight congestion in the East by the use of motors to haul high-grade goods rather than use freight cars, but a branch of the Government was practically prohibiting the building of roads on which such motor trucks could be used.

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No. 1602*h*

ARMY TRANSPORTATION

By Major L. B. Moody,[1] Washington, D. C.
Non-Member

THE question of army transportation is a pretty broad one, and in general it comprises very broad and distinct classes of service, all back of the fighting lines. When you go into the zone where troops are operating the first assumption is that there is no road, and also that transportation becomes specialized; that is, the Medical Corps do not want their patients handled on the cubic-foot or pound-per-mile basis. Likewise the engineers have special apparatus, such as portable searchlights and demolition equipment. The Signal Corps has its wireless outfit and equipment for their aeroplane service, etc. The Ordnance Department depends on the motor transportation, as it furnishes all the field guns and the materials known as munitions.

When the question of replacing the horse in this special service came up, it was referred to the Ordnance Department. There is no serious difficulty in replacing a horse where you have a road; but where you have no road and where you have got to be 100 per cent certain that you will arrive at your destination, that is where the difficulty of replacing the horse with the fighting troops has come in. That is, if the general supply trains fail on the main roads, it is possible that the men might go hungry for a day. But, if on the other hand you wish to use a gun for a certain purpose, it is of no use to have it arrive a day late — it must be there on time. That has led to special forms of transportation.

As to the volume and the organization, it can be said that practically every gun handled by the United States Army will be handled by motor equipment; and if we get an army approximating in size those on the other side you will obtain some idea from the number

[1] Carriage Division, Ordnance Department, U. S. A.

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of guns engaged of the magnitude to which this important matter of transportation has now grown.

I do not want to say our problems are solved, as they are not, but from operating the experimental equipment we had at the middle of April last, we have progressed from one officer in charge, a couple of officers, and a couple of draftsmen and five desks, to the point where we have schools turning out men to repair these trucks at the rate of 30 to 50 trained officers and several hundred trained men every month. We have estimated the number of men actually building these trucks (not counting those in related industries) and they number about 50,000. The number of officers actually on duty is from 300 to 400, the number of enlisted men runs into the thousands, all for repairs only.

The cost of this will exceed that of the Panama Canal, and the Ordnance Department has expanded something like forty times, by actual count, in the last eight months of its history.

We are endeavoring in the department to handle this problem ourselves, but we would have made but little progress but for the assistance received, particularly in my section of the Ordnance Department, primarily from the Society of Automobile Engineers, and from those among our officers who belong to The American Society of Mechanical Engineers or who would be eligible for membership. Without the assistance of these trained men it is safe to say that we would be nowhere.

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No. 1602*i*

THE AIRCRAFT PROBLEM

By W. F. Durand, Washington, D. C.
Member of the Society

IT is perhaps fair to say that when hostilities were declared last April, no one at that time in connection with the Government had any vision of the part which the Air Service was destined to play in the plans which were soon to be developed. It is perhaps further fair to say that it was not until the visits to this country of the Balfour and Viviani-Joffre missions that these ideas began to crystallize into definite form. Very promptly, however, they did commence to so crystallize, and we began to get some vision of what the Air Service might possibly mean. Immediately there arose a series of the most important problems which have ever been presented to the United States and to her engineers in an engineering and industrial way.

I have jotted down a few of these problems, as follows:

1 Of the various types of machines, fighting, reconnaissance, bombing and training, what number shall be set as a goal for active service at one time?

2 What wastage in such machines is to be anticipated?

3 In consequence, what numbers in each type must we be prepared to build within a twelvemonth or any other specified time?

4 How many trained aviators will be required to maintain the desired number of machines in active service?

5 How many men must be put through preliminary training in order to secure the needful number of active aviators with the necessary reserves? Or, in other words, how much raw material must be handled in order to secure the necessary amount of finished product?

6 How many mechanics and repairmen will be needed to keep this fleet of airplanes in all classes up to "concert

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pitch," and ready for instant service at any time and at all times?

7 Where and how are we to undertake to build the number of airplanes indicated as necessary as the gross output, say for a year, in order to maintain the fleet continuously at proper strength? Or, put otherwise, we may perhaps well ask, What is the maximum number of airplanes which can be built in those various classes in the United States, or by the United States, without undue disarrangement of either needful war industries and of the irreducible minimum of peace industries?

8 To what extent will further demands be placed on air productive capacity by demands of our allies in Europe for airplanes or engines in types which we may hope to produce with high economic efficiency? and to what extent may we expect to draw upon them for certain types — as, for example, the fighting scout — thus relieving the United States to some degree of attempting, at least at the start, to produce this final word in the evolution of fighting aircraft, as developed on the battlefields of Europe?

9 To what extent will the demands of our allies call for raw material, such in particular as airplane timber? Will the total demand exceed the presumable supply, and if so, to what substitutes may we turn?

In considering this question, certain conditions are obvious. There is no use of talking about an air service if the number is to be limited to hundreds. If we have any vision of the activity and efficiency of air service as now conceived, it must mean the production and operation of airplanes in large numbers, measured in units of thousands and not hundreds. We must therefore fix as a number, in order that it may have any significance in the problem, one measured in thousands. If we can say five thousand, it is well. If we can say more, it is better. There is no definite answer to this question; but we are committed to maintain airplanes, once we are under way, in many, many thousands.

Again, what wastage in such machines is to be expected? That is a matter of statistics, and the data for the accurate determination of the answer to this question are not available. The data are contradictory. We lack definite information as to the average life

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of machines. Under certain conditions one may continue in active service a month, a week, or perhaps a day. But machines do not fly every day; conditions of weather intervene, and of the 365 days of the year only a fraction of them will be available for the fighting machines on the front. So, taking the average, we get to the approximation that the effective life of the machine will be several weeks, possibly two or three or four months.

In consequence, what numbers in each type must we be prepared to build within a twelvemonth or any other specified time? This is tied up with the question, How many can we build? And the answer is the same. We must be prepared to build airplanes in thousands. We must be prepared to build a multiple of the number in active service at any one time. If we are to maintain 5000 airplanes in active service at one time we must be prepared to supply during the twelve months a multiple of three, or four, or five or six times that number.

HOW MANY AVIATORS AND MECHANICS DO WE NEED?

Again, how many trained aviators will be required to maintain the desired number of machines in active service? Obviously, there must be one for each machine in service. With modern machines, carrying more than one man, we must maintain in active service more than one man in each machine. There has been a tendency not always to insist upon the capacity to handle the machine on the part of every man who goes up. A man may be a good observer without being a good pilot. But this is not a good ideal. We believe that no man should go up in a machine for any purpose whatever without his being able to pilot the machine; to manage the machine in case the regular pilot is injured or killed, and to bring the machine back within our own lines. That means there must be a number of men trained for auxiliary service, but with a given minimum of skill. It is obvious the number of men we must be able to turn out in the course of a twelvemonth must be measured in units of several thousands. Five thousand would be minimum, and we must look toward some multiple of such number.

With regard to the actual provision for meeting this requirement, it is perhaps proper to give some idea of the capacity of the schools now occupied in this particular work.

The first step in training an aviator is to give a brief course of eight weeks in the so-called ground school. This is a school intended for preliminary instruction, not including work in the air. It in-

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cludes elementary instruction in the principles of flight; in the principles and operation of internal-combustion engines, meteorology, photography, scouting, machine-gun work, reconnaissance work, and comprises lectures, class work and laboratory exercises in these subjects. This course runs for eight weeks.

The course contemplates the feeding in at these institutions of twenty-five candidates per week, and the feeding through and graduation each week of whatever is left of the twenty-five, taking into account the wastage. Without wastage it would mean twenty-five per week for each school to go to the flying schools; and with eight schools there would be about two hundred cadets a week, or something of the order of ten thousand per year.

There would be, necessarily, a considerable wastage, and perhaps not more than one-half of that number can be expected to realize an efficiency which will make them significant units in the program as time goes on.

The capacity of these schools could be multiplied, and such multiplication is now in process of development. There need be no ground of apprehension about training these men, assuming that we can obtain properly qualified young men, with the necessary personal, physical and mental characteristics such as are needful to enter into the composition of the bird man.

It is true that of men qualified for the last and highest degree, men whose nerves and muscular reactions are such as to make them react instinctively — as bird men — the number is small. But, on the other hand, every well-built, normally developed and endowed young man is able to develop a degree of skill adequate to render him an effective unit in one place or another in the air service, even if only a few reach the supreme excellence which we see in some of the specially trained airplane fighters.

The number of these engineering, technical and scientific schools can furthermore be multiplied two, three or four, and the capacity of each can be multiplied perhaps by two, on the average, and we thus have abundant possibilities for the development of a very large amount of material for ultimate service in connection with the plans now in formation.

The number of mechanics and repairmen is again a matter of experience, and it is found that for every airplane there must be one specially skilled mechanician who will give his entire time to the maintenance of that particular machine; and for each group of twelve, twenty-four or thirty-six, there must be an additional num-

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ber, and in the base supply depots and other points back of the line there must be others.

If we go back to the supply of gasoline and lubricating oil, and to the supply of elements of that character, we may greatly multiply the number of men necessary to maintain in a state of efficiency any one airplane. But stopping short with the number of men concerned with the machine itself, we must multiply the number of aircraft by three, four or five.

If we take into account the number of fliers contemplated and the number of mechanics and repairmen behind the line in one capacity or another, it results that the contemplated officers and personnel of the Signal Corps will exceed the entire standing army at the outbreak of the war.

HOW WILL WE MAINTAIN OUR AIR FLEET?

The next question: Where and how are we to undertake to build the number of airplanes indicated as necessary as the gross output, say for a year, in order to maintain the fleet continuously at proper strength? Or, put otherwise, we may perhaps well ask, What is the maximum number of airplanes which can be built in those various classes in the United States, or by the United States, without undue disarrangement of other needful war industries and of the irreducible minimum of peace industries?

Now this question No. 7 comes closest to us as engineers and men concerned with the industrial affairs of our country. Where and how are we to undertake to build the number of airplanes indicated as necessary as our gross output? Where to find and how to develop the tremendous extension in the industry necessary to provide this enormous number of airplanes for immediate production? It means the development of an industry, highly trained and highly specialized — not, indeed, out of nothing, but out of very small beginnings. Perhaps I should say that it meant the crystallization of the elements of such an industry. And it was splendid that there were found shops, and trained personnel and equipment and organization for the production of airplanes, right in the automobile industry. It meant, nevertheless, an enormous extension in productive capacity beyond any vision which the wildest flight of imagination could have contemplated a few months ago.

Only a few weeks ago I was able to visit, by way of inspection, three of the principal centers of airplane production at the present time — Dayton, Ohio, Detroit, Michigan, and Buffalo, New York.

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There we saw new factories which were either completed and occupied or on the point of occupancy, aggregating something like thirty-five to forty acres of ground area, to say nothing of the gallery space.

Furthermore, there was ready for immediate expansion perhaps twenty-five to forty per cent in addition. It is fair to say that early in the next year there will be occupied actively in the production of airplanes something like fifty acres of ground area, with their gallery space, which did not exist eight months ago. And this is without taking into consideration the automobile factories. Acres upon acres of area in existing automobile factories are running solely on airplanes and airplane parts; and we are just on the edge of a period of very large production.

The period which has elapsed since last June or July, when the present program began to crystallize into reasonably approximate and definite form, has been necessarily spent in measures of preparation for this tremendous program of expansion and industrial development. And we may certainly anticipate within a few months, say two or three at the latest, that this factory capacity will be actively occupied in turning out airplanes at the rate of at least several thousand per month. The precise number I hesitate to define more closely at this time.

WHAT FURTHER DEMANDS WILL ARISE?

The remaining questions I will touch on more briefly. They are: To what extent will further demands be placed on air productive capacity by demands of our allies in Europe for airplanes or engines in types which we may hope to produce with high economic efficiency? and to what extent may we expect to draw upon them for certain types — as, for example, the fighting scout — thus relieving the United States, to some degree of attempting, at least at the start, to produce this final word in the evolution of fighting aircraft as developed on the battlefields of Europe?

The other one, the ninth, is: To what extent will the demands of our allies call for raw material, such, in particular, as airplane timber? Will the total demand exceed the presumable supply? and, if so, to what substitutes may we turn?

It is sure that the demands of the Allies will put to the test every bit of our productive capacity for airplane material. We are now making for them flying boats in large numbers, and they are looking more and more to us for the production of airplanes for the

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training of aviators. In fact, the nearest approach to the standardization of a definite type is the American type, for at least the American, Canadian and British services. And they are coming to look to us for other types as well, and for the production of airplane engines.

The demands for supplies are also at the limit of our productive capacity. The demand has been incessant for timber — spruce, spruce, and again spruce! Serious difficulties have been met with on the Pacific Coast in the way of supply, but on the whole the prospect seems to be improving.

Substitution of other woods has also been introduced in some measure, which, while they have different characteristics from spruce, yet give effective service. And then there are suggestions in the way of metal substitutes which seem to hold hopeful and interesting possibilities.

THE PROBLEMS OF STANDARDIZATION

One of the questions which presented itself again and again, and aside from the questions of policy or program a question which is vital to the engineer, is that of standardization — standardization of elements and standardization of types. I need not take your time with a statement of the advantages of standardization of parts used in large numbers.

The standardization of elements, such as screw threads and fastenings, has progressed very satisfactorily; and for general airplane parts much excellent work has been accomplished through the efforts made by the Society of Automotive Engineers. And there is to be held soon in London an International Standardization Congress to which this Society has been asked to send a representative, and I understand that this Society will have one of its eminent past-officers at this conference as its representative and at which we may anticipate a still further approach toward standardization by way of elements and parts.

The other problem relates to the standardization of types, but here is danger. It is necessary to standardize; but it is fatal to attempt to standardize a type too rigidly, because if we know anything at all from experience on the western front it is that a type has no longer begun to prove a measurable degree of success than it is put out of date by the appearance of some new and improved type; and so as the weeks go by one type comes along after another.

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The entire program must be based on the expectation of displacing from time to time types which for production purposes may be standardized for the time being, but which cannot be kept in production too long after the development of more efficient types.

I have tried to visualize this as a tremendous stream of production. Parallel with this stream of production we must have likewise a stream of development, research, investigation and a program which is seeking to contact with the unknown and the new; developing, judging, testing and determining their technical characteristics and their adaptation to the conditions of active service. And so fast as new types and forms are developed and proven superior, just so fast must they be fed into the stream of production, taking the place of out-of-date forms. Only in this way can we maintain the types and forms in use at the front responsive to the advance in the science and art of airplane production, and responsive to the conditions at the front and which must determine the characteristics of the material to be supplied at the fighting front.

THE SO-CALLED LIBERTY MOTOR

I should not close my remarks without saying a word regarding the attempts to standardize the airplane motor. You are all familiar with the story of the design and development of the so-called Liberty motor. I will not go into that at all. But you can appreciate the fact that of the various problems requiring standardization, that of the motor was one of the most important. The question was, Shall we copy outright a European motor? Shall we copy outright the best American motor? Shall we combine the best in American motors and make a new motor? or shall we combine the best in European motors? or shall we combine the best in European and American practice and call that the standard motor?

In effect, the latter was the program undertaken. Drawings of European airplane engines and to some extent actual engines were available in May and June when the characteristics of the Liberty motor were determined upon. The characteristics of the best in American practice were naturally present in the minds of the designers, and on the basis of this and the best information from Europe and this country, the determination of the characteristics of the Liberty engine was developed.

The first engines, as you will remember, were built in an astonishingly short period of time, a matter of twenty-eight days from the time two men sat down in a room at the Hotel Willard until a

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motor was set up, and two days later was ready for test at Washington.

Then there was the question of the anticipated "teething troubles." The motor has been taken to Pike's Peak and sent up the grade and tested at various altitudes; and while there have been varying reports in the public press in regard to this motor, I wish to say that the reports in some degree unfavorable which have emanated from certain sources have not been well founded. The motor has met and is meeting the full expectation of its designers. It has had, as every design is expected to have, minor difficulties and troubles, but not one of them has been fundamental to the motor itself, and they all readily admit of correction and removal; and means have been found for the improvement and correction of such troubles and the motor is now in course of active production and on a large scale.

A few days ago we saw in Detroit in one of the factories there the process of manufacturing the forgings of the Liberty motor cylinders. All of the forgings are being made in one plant, and that plant is to supply the trade with Liberty motor cylinders. The forgings are made by a hot-forging process from seamless tubing, and they were being put through at the rate of 1200 cylinders per day. The factory was planning to double that capacity and they are ready to go still further and increase capacity as the needs require.

Perhaps in conclusion I should mention two or three problems not solved yet and which are of special importance, and which I shall take the liberty of calling to your attention and recommending to your special thought and study.

One is the supercharging airplane engine: the engine which shall be supplied with means to secure the maintenance of the power at high altitudes, and not suffer the loss normally attendant upon working in a rarified atmosphere. If we have the same engine working at sea level and then soaring upward, it is found that the power diminishes with the density of the high-altitude atmosphere. Many devices have been suggested, but the problem is to realize the end in the most effective way and with the least cost in excess weight and added complexity. If we can solve this problem we can assure our supremacy in high-altitude service.

Another development is that of modifying at will or automatically the pitch of the airplane propeller. It is of small use to maintain power if the propeller is to maintain its same pitch in an

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atmosphere of reduced density. The engine will speed beyond the limit, or the rotation speed of the engine will impose a limit upon the power which could be developed.

Some way or means is required, therefore, for properly modifying the pitch of the propeller in order that we may without undue sacrifice of efficiency cause the rotative resistance of the propeller in a rarified atmosphere to correspond in some degree to the continuing torque of the engine.

Another problem is that of the spark plug. The modern spark plug has been a development in response to automobile conditions, in response to the compression pressures which prevail in automobile practice. It is found that under the higher pressures in aeronautic service the spark plug, based on the automobile program, rapidly breaks down. The insulating characteristics are lost in one hour or two hours or ten hours, and there is a bewildering uncertainty as to the life of the spark plug under present conditions. This is one of the outstanding problems, particularly with reference to the increasing demands of modern airplane service.

One final thought is this: Throughout this trip of inspection we were very strongly impressed with the serious purposes with which the captains of industry in this field of production are approaching this problem. They realize its magnitude and its importance, and they are approaching it with high purpose and patriotism; and with the presence of such a pervading spirit in the industries of this country we are going to make good with regard to our program of airplane production. Not quite what was hoped, perhaps, in the first flush of anticipation, but we are going to make good, and the production in airplane manufacture will not be our least contribution toward settling this world war, and toward settling it in the way we all hope it will be settled.

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No. 1602*j*

THE SOLUTION OF THE CANTONMENT-CONSTRUCTION PROBLEM

By Leonard Metcalf, Boston, Mass.
Member of the Society

THE Cantonment Construction Division is an organization which did not exist six months ago, but which has built in this incredibly short period of time sixteen National Army cantonments, with 26,500 buildings to house and care for 675,000 men; two embarkation camps for 43,000 men; one quartermasters' training camp for 18,000; additions to the regular army barracks, for 100,000; repair-shop units; and the semi-permanent structures at sixteen National Guard camps, to care for 462,000 men; and which has designed and purchased equipment for certain large plants for our army in France, a tremendous task involving 200,000 men and an estimated cost of approximately $187,000,000, over three-fourths of which has already been spent. The story of this work is a wonderful one, not of planning and preparation, but of doing seemingly insuperable tasks daily, an inspiring story of loyal and effective coöperation between army officials and civilians, the one with army traditions and experience, the other with their widely different professional and commercial training.

The cantonment work is done — a splendid achievement, creditable alike to the Government, to this bureau of the army, to the construction quartermasters at the camps, to the supervising engineers and contractors, to the railroads and supply men, and to all concerned.

Not a sandpapered or polished job, but rough-hewn, strong and calculated to serve. Wasteful in certain details, no doubt, but economical in the best sense, for the saving in time here has saved life and treasure on the long firing line across the water.

Where can you duplicate the experience, involving as it does an expenditure of $150,000,000 in six months' time — three times the

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maximum rate of expenditure in twelve months on the Panama Canal — and which increased tenfold the normal building activities of the country without substantial increase in the cost of materials from beginning to end of the task, due largely to the work of the War Munitions Board of the Council of National Defense and its committees; involving meager compensation to the administrators, designers and supervisors and voluntary service on the part of many skilled advisers, who dropped important personal obligations to go to Washington for days, weeks or months in response to telegrams asking for help; voluntary coöperation and work by the railroads, telephone, electric and other utilities, and substantial expenditure without guaranty of return; contractors taking contracts to build structures estimated to cost from $3,000,000 to $4,000,000 and actually building these and many additional structures so that the final contract sums ranged from $8,000,000 to $10,000,000 per cantonment, nearly doubling the necessary construction period, but without increase in compensation, and this when the compensation upon the building of the National Army cantonments was limited, not to a profit of 10 per cent, as has so often been stated, but to a gross return of $250,000, averaging for the sixteen cantonments less than 3 per cent, out of which sum had to come an overhead expense of probably $100,000 and interest charges upon $600,000 to $1,000,000 of working capital amounting to perhaps $25,000 to $40,000 more, leaving a *net profit to the contractor of substantially less than 2 per cent?*

Broadly speaking, labor costs alone have risen, following closely the local cost of union labor for an eight-hour day, with time and a half or, in some cases, double time for overtime, according to the prevailing local conditions; and even as to these, there are the extenuating circumstances of increased cost of living, the fact that the settlement of the labor rate disputes was not always left to this Board for solution, and, most serious of all, the failure of the Government to adequately control priority of its construction, which would have prevented the bidding up of the local labor markets by its own agents in different departments having contiguous construction underway.

I speak advisedly, not loosely, for the conditions of the work may not equitably be overlooked. They are vital. The work had to be done, *was* done, without delay, and no plea or excuse of inability to get labor throughout the work at rates prevailing at its inception would have excused postponement of completion or have brought back life or treasure spent at the front during such delay.

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CALL COMES FOR ORGANIZATION

On May 17, 1917, Brigadier-General I. W. Littell, then Colonel of the U. S. Quartermaster Corps, was detailed by the Secretary of War to assemble and direct an organization to be known as the Cantonment Division of the Quartermaster Corps, to provide facilities for training and housing the new National Army and the National Guard. He called to his aid Major, then Captain, W. H. Oury, Major, then Captain, R. C. Marshall — both of the Regular Army, and Major Dempsey of the Officers' Reserve Corps, the former of whom had been supervising the enlargement of some of the army barracks, the second of whom was soon engrossed in the new cantonment construction, and the last of whom took up the question of auditing construction expenditures.

Neither funds nor quarters nor personnel were available for the designated service, for the appropriation bill which carried $77,000,000 for the inception of this work was still in debate in Congress.

This was the opportunity of the Committee on Emergency Construction of Buildings and Engineering Structures of the War Munitions Board of the Council of National Defense. Of the latter Board Frank M. Scott, of Cleveland, was the able chairman.

This committee was made up of five experienced builders: William A. Starrett, of New York City, architect and formerly of the building firm of Thompson-Starrett Company, Chairman; C. W. Lundoff, of Cleveland, Ohio, President of the Crowell, Lundoff, Little Company, building contractors; M. C. Tuttle, of Boston, General Manager of the Aberthaw Construction Company; Capt. Wm. Kelly, of the U. S. Engineer Corps, who, however, was unable to give much time to the work of the Committee, owing to other army obligations; and Frederick Law Olmsted, of Boston, engineer and landscape architect. To their assistance they called many engineers, city planners, architects and specialists of different kinds, to act on sub-committees or to give desired advice on special subjects.

Circumstances thus made it possible for the Committee to render General Littell service in an advisory capacity on the formation and civilian personnel of his organization, on the form of contract under which the work should be built, on engineers, city planners and contractors of responsibility to design and build the cantonments, and at the moment to make the most of the time which might elapse before the appropriation bill should be passed by Congress, by preparing typical plans or layouts for the buildings and other structures involved, making topographic plans of the sites, studying the

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water supply, sewerage and other public-service facilities, the best arrangement or grouping of structures, adapting the typical plans to the local topography — all through the voluntary service of architects, engineers and city planners.

ORGANIZATION ADOPTED BY GENERAL LITTELL

The organization proposed by the Committee and adopted by General Littell comprised four different groups, reporting to his staff officers:

MAJOR FRANK M. GUNBY, member of this Society and formerly associated with Mr. Charles T. Main of Boston, *in Charge of Design;* assisted by Major F. B. Wheaton, Captain Doten, Dabney H. Maury, Clarence Goldsmith and W. M. Johnson of the National Board of Fire Underwriters, and George Gibbs, Jr., of Boston.

MAJOR ROBERT E. HAMILTON, formerly Purchasing Agent of Stone & Webster, *in Charge of Materials and Transportation.*

MAJOR M. J. WHITSON of Seattle, formerly partner of Grant, Smith & Co., *in Charge of Construction;* assisted by a staff of division engineers, Peter Junkersfeld, Charles L. Parmlee, Ezra B. Whitman and others.

MAJOR DEMPSEY, *in Charge of Accounting.*

Since that time, benefiting by the earlier experience and with a view to handling the additional work of building ports of embarkation, ordnance depots, coast-artillery posts, medical department construction, mobile ordnance school barracks, quartermasters' warehouses and miscellaneous plants, the organization has been enlarged, modified and strengthened, Major Marshall remaining in command under General Littell, assisted by Captains Thompson and Maupin; the engineering branch being still in charge of Major Gunby; the construction of Majors Whitson and Junkersfeld; the materials of Major Willcutt; finance and accounting of Major Dempsey; construction and repair of Major Zollars; the law, Major Shelby; information, Captain Erck; transportation requisitions, Captain Ritche and Chief Clerk Moreland; and several other engineers of large reputation and breadth of experience, such as Lincoln Bush, Major Betts, Warren R. Roberts, and others, have been drawn into the service — fine examples of personal sacrifice.

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The Committee on Emergency Construction of Buildings and Engineering Structures first undertook to get local investigations under way and the preparation of typical building plans. As soon as cantonment or camp sites were designated by the department commanders, approved by the army staff and reported to General Littell, city planners and consulting engineers were asked to go to them, voluntarily and at their own expense, to make topographic maps, study the water-supply and sewage-disposal problems, the location of railroads, roads and other utilities, and to report to Washington with all despatch. Within a week's time, in a number of cases, topographic maps were prepared of areas of from 1000 to 2000 acres and essential information was obtained upon the points desired. Meanwhile, leading architects and engineers of this section of the country had been summoned to Washington to assist in the revision of the plans for the barracks, the preparation of typical plans, which were afterwards adapted to the local topography, on the ground, by the staffs sent to the individual camps.

FORM OF CONTRACT PREPARED

Contractors, too, were assembling in Washington to see if they could be of service and the Committee directed its efforts to the preparation of a form of contract under which a work of the magnitude then contemplated and since largely increased, could be built with reasonable certainty within a time limit of ninety days, in the face of congested transportation conditions, soaring materials and labor shortage.

A form of contract inducing speed was essential. This compelled the elimination of the financial hazard to the contractor, and for the protection of the Government the selection of contractors solely on the basis of experience, merit and integrity. It was at once apparent that the competitive form of contract dictated by past Government precedent was out of the question with the time limit available and the conditions to be faced.

The lump-sum-profit basis form of contract was weighed and rejected as likely to emphasize the idea of barter and trade rather than of fitness and competency, and to embarrass the Government in awarding contracts to more experienced contractors if lower profit basis were offered to the Government by less experienced or less desirable men.

The cost-plus-percentage basis, however, appeared to meet the fundamental requisites, and the addition of a limiting lump-sum

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profit made the Government safe in its operation in the event of substantial increase in the amount of work done under it. The combined efforts of many able men — lawyers, engineers and contractors, as well as of various engineering organizations, produced the "Emergency Construction Contract" — a radical departure from Government precedent — which provided essentially for the construction of the work on the basis of cost plus profit, the latter varying from 10 to 6 per cent with the magnitude of the work, with the important limitation of an upset profit of $250,000, from which sum, however, the contractor had to meet his own office overhead and interest costs. It is interesting and but fair, in the face of some of the unfounded public criticism which has been heard, to note the effect of this upset limit of profit. On the construction of the sixteen army cantonments, involving a total cost of approximately $134,000,000, or upward of $8,000,000 per cantonment, the nominal profit to the contractors will be less than 3 per cent, and after deducting the probable contractor's overhead and interest costs, the *actual profit* substantially less than 2 per cent — in some cases perhaps less than 1½ per cent. Upon the construction of the National Guard camps, involving a total cost of $36,000,000, or about $2,250,000 per cantonment, the contractor's fee is higher, approximately 7 per cent, but as the overhead cost is also proportionately much higher the total return in cash for the six months' period of work is substantially less than in the cantonment construction.

Inasmuch as nearly all of the war construction work now being executed by the Government is being done on an emergency basis, where speed and not cost must control, thinking men will be careful not to criticize carelessly and will weigh fairly the influence of the time element. In the execution of work on such a tremendous scale, under prevailing labor and material cost conditions, it is inevitable that money will be wasted and mistakes made, but the work must be done — expeditiously done — that the saving may be one of lives and days, not dollars.

While the preliminary investigations were under way, the Committee sent out questionnaires concerning contracting firms in this country, seeking references, a statement of the magnitude and kind of work executed during the past two years, the number of men handled and fed at one time, and the financial resources of the concern; obtained the rating of the contractors by important financial-credit concerns, and called to its assistance John H. McGibbons,

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formerly of the U. S. Fidelity & Guaranty Company of Chicago, to aid it with his broad knowledge of the standing and financial credit of contractors.

COMMITTEE SELECTS CONTRACTORS

Armed with this information a sub-committee of five men, with Mr. Starrett as chairman, selected the contractors deemed best qualified at the moment to undertake the work and who had demonstrated in their past experience their ability to handle work of such a character and upon such a scale; and reported its findings to Mr. Scott's committee of the War Munitions Board. From the latter committee, recommendation passed to General Littell, and after submission of the evidence and recommendations to the Secretary of War, appointment was finally made by General Littell. The subsequent experience in the building of the camps seems clearly to have justified the course of procedure, and it is greatly to the credit of the Government that it can be said, unequivocally and with absolute candor, that these appointments were made on the merits of the case, as they were understood, without political pressure or "influence." It is further greatly to the credit of the leading firms of contractors that as a rule their representatives left Washington before they knew whether they were to be recommended for specific work and before appointments were made, though personal disinterestedness and unwillingness to use political influence cannot be claimed for many others who sought contracts.

The Committee then turned its attention to the preparation of forms of contract for the employment during construction of the engineers and other experts necessary at the camp sites, being greatly assisted in its work by different members of the national engineering societies, who voluntarily came to Washington in response to telegraphic request, to assist the Committee.

Engineers believed to be most competent and at the moment available for service at the various cantonments were also designated, appointments in all cases being made, of course, by General Littell and his staff.

In this way the Government had the voluntary service of many men — skilled in the particular field involved — in building up an effective organization and personnel for the work in hand; men who coöperated in a thoroughly disinterested way with the administrative army board in responsible control. The results attained here seem to indicate the advantage of such a purely advisory

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board, the recommendations of which could be followed, modified or rejected with cause by the duly constituted executive authorities.

DETAILS OF CAMP CONSTRUCTION

Time forbids the attempt to chronicle the details of camp construction executed under the direction of General Littell and his staff. The sixteen National Army cantonment sites were approved at various dates ranging from May 31 to June 27, 1917, contracts for their construction were executed between June 15 and June 23, and work was begun between June 13 and July 6. On September 4, or in less than three months' time, about 450,000 men could have been taken care of at the cantonments on the first-adopted basis of 200 men to the barrack — later reduced to 150 men; and today, December 5, 1917, the camps are substantially all completed, despite the great increase in construction involved by the prescribed increase in cubical air space per man in the barracks (from 365 to 500 cu. ft.), the addition of remount stations, to care for 10,000 horses at each of the camps having them, hospitals and other changes, which have nearly doubled the work originally contemplated.

The story of the construction of the National Guard camp equipment is similar, except that the work involved is only about one-fourth of that involved in the construction of the cantonments.

A few figures in regard to the magnitude of the work involved in building the sixteen National Army cantonments may be suggestive. There were required upward of 800 million feet, or 37,000 cars, of lumber, and 40,000 cars of other material, a total of 77,000 cars upon the cantonment construction, without allowance for the materials ordered locally and not from Washington — the total involved in the cantonment, camp, and embarkation-station construction to October 31 being approximately 112,000 cars — 756,000 squares of sheathing paper, 800,000 of roofing paper, 172,000 doors, 34 million square feet of wall board, 106,000 kegs of nails, 314,000 barrels of cement, 282 miles of wood and cast-iron pipe, 3550 hydrants, 75 miles of fire hose. The total area of land rented or controlled at the cantonments is 261 square miles.

As the construction of the cantonments was drawing to an end the work of this bureau was extended to cover the construction activities of the army, except in a few special cases, such as in the aviation corps, where it was thought wiser by the Secretary of War

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to leave the construction in the hands of the departments for the use of which the structures were to be built. This new work is well under way, constantly growing and broadening.

WHOLE WORK MONUMENT OF LOYALTY AND ABILITY

As one reviews the work accomplished by this cantonment division, he cannot but be thrilled by this fresh evidence of the resources of these United States and the loyalty and ability of its people, remembering how recently and in what manner this bureau was organized; that cantonment construction involved but one branch of governmental activity and one comparatively small group of men; and that similarly inspiring evidences of effective service are to be found in all of its other branches.

If constructive criticism is warranted at such a time, it may be said that one of the greatest needs today, as it was recognized to be six months and more ago, is better coördination of the governmental construction program, ways, means and priority. The subject has been studied in its various phases by many men, but no sufficient authority has yet been delegated to accomplish substantial progress. Effective organizations of thousands of men have been built up with large expenditure of time and money, only to be disbanded on the accomplishment of their specific tasks, when these organizations might have been transferred directly to new tasks, with telling effect, had there but been the necessary Government authority to plan well-coördinated effort in its construction field.

In an emergency of the magnitude created by this war, and in the face of the Government's failure to prepare for it, the question immediately arose as to the basic principle which should govern the selection of the agencies to accomplish the enormous task before the Government. Should the governing bodies be creative or essentially administrative? For instance, should the necessary design of warehouses, hospitals, power plants, terminals, nitrogen- and gas-producing works, engine and aeroplane construction, and other work, be executed by old governmental bureaus with greatly enlarged personnel, by new governmental bureaus to be created solely for this purpose, or should it be entrusted, under proper governmental supervision, direction or control, to well-established, adequate and efficient engineering organizations, skilled along these lines and competent to handle the work, of which organizations there were many in the country? Similarly, should the different army corps, with totally inadequate personnel, act as purchasing agencies, or

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should this highly specialized work be delegated, under governmental supervision, to existing firms of high capacity and reputation?

Mr. Balfour, in his visit to this country, had wisely cautioned against the mistake made and the loss of time incurred by England in building up new bureaus to do the work before the Government, instead of utilizing well-established and live organizations enlarged and controlled by the Government, if necessary, to the end not only of saving time and expense, but also that when the war was over the gigantic work of reconstruction and readjustment might be facilitated by the enlargement and strengthening of these existing private or corporate agencies, instead of being retarded and hampered by their disruption.

The Committee on Emergency Construction had this thought clearly in mind and predicated its efforts on the three hypotheses:

1 The work must at all times be under the superior control of the United States Government, through its duly accredited representatives
2 Services must be equitably compensated
3 Government methods of contracting for and compensating construction work and services should be such as to utilize and strengthen and not to impair or destroy existing organizations.

Unfortunately, the Government has not carried this principle as far as it might advantageously have done, but has in a number of cases built up in Washington and elsewhere new agencies for executing work instead of employing existing ones competent to render effectively the service desired, thus failing to benefit by the mistakes of England and France and the helpful advice of Mr. Balfour. But, on the whole, and in spite of the waste thus involved, surprisingly rapid and very commendable progress has been made.

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No. 1603

THE NATION'S CALL TO THE PROFESSIONAL MAN

By Hon. William H. Taft, New Haven, Conn.

IT is a great honor and pleasure to be here in this company to take part, if I may so say, in your act of recognition of one of the world-reputed members of the general profession of engineering. Major Goethals, as he was when I first knew him, did build the Panama Canal, whatever he says and whatever he claims. I am able to testify to it, because I was there for eight years and saw him do it, and I know the trouble he had. I know the struggle he had. I know the power of the man in meeting difficulties. I know his tenacity of purpose. I know from its results, not from my professional knowledge, but from its results, his wonderful ability as an engineer in all the fields of engineering, because that task commanded a knowledge of every branch of engineering. I know his power for managing men. I know of his genius of common sense, without which it would have been impossible for him, in face of the difficulties, to discharge the task which he did discharge, and I may say, because an ex-President out of office can say anything — so long as it is truthful — that I am profoundly regretful that the United States and the people of the United States in this great juncture, in this great crisis, have not the benefit of the great ability and great experience of General Goethals. (Loud applause.)

I was a lawyer and I was a judge, and I was sent to the Philippines. I was sent there — well, I don't know why, but there was more excuse for sending a man there who did not know anything about the subjects with which he was to deal in the Philippine Islands, because there were very few men who did, than there is for putting any man in a position now who does not know a great deal about the subject in respect to which he is to discharge his functions. But, as I say, I went to the Philippines, and while there it fell to my lot to be responsible for some engineering tasks.

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers.

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We had to do a good deal of engineering in the Philippines, and I came in contact with that very distinguished body of men who have vindicated their existence many a time, and have inspired great confidence in them on the part of the people of the United States — the Engineers of the United States Army (applause), of which General Goethals is a world leader.

And then, when I came here as Secretary of War it fell to my lot to be associated with engineers, civil engineers, who were called in to assist in the determination of a problem that had to be met and solved in the construction of the Canal, and I look back upon my association with men like Alfred Noble; Stearns, of Boston; Freeman, of Providence; Randolph, of Chicago; Parsons, of New York, who is now at the front, and other engineers, with profound satisfaction. (Applause.)

ENGINEERS AND MEDICAL MEN INDISPENSABLE

Now, you engineers, all, constitute one of the two professions that are indispensable to the country in the carrying on of the struggle to which the people of the United States are about to devote themselves, yours and the medical profession; you as the constructors of all the material and all the equipment of which so much is needed now in modern warfare to make effective the work of our boys at the front, and the medical profession to furnish, so far as may be, the aid in restoring to the ranks those whom the fortunes of war disable.

We have a conscription law, which is justified on the ground that it was a selective draft, and we know that under that law those whose services can be most useful to the country in the trenches will be sent over, and those whose services can be most useful to the country in preparing and in saving men and material will be retained in their places at home so that they may not be wasted in the trenches and elsewhere, in which others could do just as good work as they, others who could not discharge the services required of engineers or physicians.

England has, as you know, made mistakes in her great work that she has done. I do not think we have praised England enough. I do not think we realize how much she has really accomplished. But we should profit by the mistakes which England made in allowing her doctors and her medical students, her engineers and her engineer students to go into the ranks and be sacrificed. Because of this, England has reduced the supply of those indispensable persons, so that she is embarrassed, and greatly embarrassed.

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Now, my friends, we ought not to make the same mistake. Congress and the Administration should see to it that the medical students and the engineer students should be reserved for the work for which they are particularly fitted; that the engineer students and the medical students should be required to go on and complete their preparation as engineers and physicians, so that they may become engineers and doctors, and then be gathered into the service of the Government in this war, to help the Government in those places in which, as I say, they are indispensable. (Applause.)

Now, there has been a difficulty — there seems to have been a fear that temporary exemptions would mean favoritism, and Congress and the Administration have not been as prudent as they should have been with reference to these invaluable agencies which we should make as strong and as full as possible. Congress is now in session, and therefore Congress ought to take steps to give power, if power is lacking, to the Secretary of War, to the Secretary of the Navy, the Secretary of War particularly, to deal with embryo engineers and embryo medical students, so that we may have as many engineers and doctors as we can possibly have, because we shall need them all.

Of course, other professions are helping too, lawyers and ministers — we are likely to have enough of them (laughter) — and I do not see why exemption should be claimed for them, and being a lawyer I can say so. I do not mean to say that lawyers are not patriotic, that lawyers are not being called upon now for gratuitous services which they are rendering in connection with this draft, but I do say that as a permanent thing their services are not likely directly to promote the winning of a battle like Cambrai, whereas the engineers may help; and it thrills one's American heart to know that the members of your profession, now, tonight, are engaged in exposing themselves and fighting for the great cause in which this Republic is so much interested and to which the greater part of the world is so devoted.

MUST TALK ABOUT THE WAR

I was not quite sure what I ought to talk about when I came here. What I have said up to this point, like the President's few remarks, has not been my speech. One cannot come before an intelligent audience like this and fail to talk about the war. I have talked about the war a good deal in various parts of the country and I have been impressed with the feeling that the war could be talked about

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a good deal more about the country, throughout the country, to the people of the country, with very great advantage. There are so many who are doubtful — they are for the Government and they are for the war, but they are walking interrogation marks as to whether we did not make a mistake here, or did not make a mistake there, or whether we are fully and rightfully in the war, that I think an evangel ought to be preached on the subject to demonstrate that we are rightfully in the war, that we never have done anything that was not justified, and that the cause now presented to us is so righteous that if we are the people we claim to be we must win it if it costs the last man and the last dollar that we have. (Prolonged applause.)

You meet men who are now, after we have decided to go into the war and after we are in it, who are now "judicially-minded" — that is to say, they do not say they are neutral, but they are judicially-minded. While I am in favor of being judicially-minded, I am not in favor of masquerading under a judicial mind a lack of that fine edge of loyal patriotism that we need to carry this country through the war. (Applause.) I am opposed to apathy; I am in favor of team work, and of knowing why we are in, and what we are going to do, and in favor of being determined to do it. (Applause.)

GERMANY'S BREACHES OF INTERNATIONAL LAW

You will find this judicially-minded person suggest that we were unneutral during the three years that we were not in the war, because we furnished ammunition and other supplies to the Allies. Well, we had a right to do that under international law. Germany herself had agreed to that rule of international law with respect to the power and duties of neutrals — not that neutral governments could furnish such supplies, but that neutral governments could permit their citizens to do so, the citizens taking the risk of confiscation of those articles as contraband if found upon the high seas. And there were those who sympathized with Germany after the German commercial marine had been driven from the seas, and they said it was unneutral for us to furnish one side.

The fortune of war was not our fault. The President was right in insisting that we should stand by the rule of international law in that regard, because if by our acquiescence the rule of international law were to be changed, requiring every neutral government to suppress its citizens from carrying on such a trade, it would only make overwhelming the advantages of a military nation that devoted itself, as Germany did for fifty years, to getting ready for this war, a

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nation which has piled up the ammunition and supplies needed to carry her through years of war. We, if subjected to a war of aggression, would never be ready. We would always be unprepared, and, as a consequence, when forced into war we would have to look about to prepare suddenly, and then find denied to us the right to get our material and supplies from the citizens of neutral nations, under the new rule suggested. Therefore, it would have been the wildest lunacy for us to consent to a change of international law in that regard, and the merits were wholly with the President in taking that position.

But, notwithstanding the fact that we pursued the path of neutrality as laid down by the law, Germany sank an English commercial liner having three thousand persons on board, and sent to their death 114 American citizens by the murderous torpedo which her submarine hurled at this vessel. Then for a year we continued a discussion, arising from Germany's unfounded claim that the vessel was armed; then she sank another vessel under similar circumstances; then we said that we would sever our relations with Germany; then she said that she would discontinue that method of warfare until further notice; then on the 31st of January last Germany notified us, as she notified the world, that she intended to resume the ruthless submarine warfare; then shortly afterwards we severed our diplomatic relations with Germany; then she sank four or five American vessels, returning to this country in ballast, and sent to their death some twenty-five or thirty American sailors; and then we declared that a state of war existed.

OUR DUTY AS A GOVERNMENT

Now, my friends, is there anything else that we could do but that? That is where your judicially-minded person would come in. The answer to my question depends, first, on the proposition of what were our rights, and what were the rights of our citizens? and secondly, what was our duty as a Government with respect to those rights? International law is indefinite in certain respects, but it is as definite as the law of promissory notes with reference to the rule of the capture of commercial vessels at sea. A belligerent may capture the commercial vessel of its enemy and sink that vessel. It may capture, under certain circumstances, a neutral vessel, violating a blockade, and possibly may sink it, but an incontestible rule for a hundred years has been that that right of capture and right of destruction are subject to one limitation, namely, that the

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ship's company of the captured vessel shall always be put in a place of safety before the vessel is sunk.

Admiral Semmes in the Civil War sank perhaps four hundred or five hundred vessels of the United States commercial marine, but he prided himself that in all that destruction not one single human life was lost. He was an international lawyer of repute; he was also a naval commander, and his course in that regard is the strongest evidence of what international law is on that point. Therefore, Germany violated the rights of those citizens whom she exposed to death and whom she sent to death. When a man kills another deliberately, without right, it is murder, and there is no other word nor any other term in international law that can be applied to a case where a nation kills men and women and children without right. (Applause.)

GERMANY'S WARNING OF MURDER

Ah! but it is said these people had notice. That distinguished and eminent Christian statesman, Count von Bernstorff, had whispered over the telephone and had intimated very enigmatically that any one who went aboard the *Lusitania* would run the risk of being torpedoed, and it is stated that those who went down in ships sunk afterward knew that Germany was on the sea with these murderous instruments. Well, that is a fine plea. Suppose a man in New York should warn a neighbor that he could not go down into the street upon which his house abutted, because if he did he would kill him; and suppose this man who was warned was a courageous American citizen who knew what his rights were, and he went down into the street and the threatener did kill him. Suppose that man was indicted and haled into court and called upon to plead, and he pleaded not guilty on the ground that he had notified this man that if he would come down into the street he would kill him, and therefore he was not guilty because the man himself was guilty of contributory negligence in running into a bullet whose presence on the street he ought to have anticipated. (Applause.)

But Senator La Follette says — (Hisses on the part of some persons in the audience.), oh, don't hiss, it never helps to call names, no matter how poor an opinion you have of a man, it does not help the argument — but Senator La Follette says it is true they had the right to be where they were, but those were technical rights. It is too bad when a senator in Congress, sworn to obey the Constitution, should regard the right of those poor victims on board the *Lusitania*

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to life and the right to protection against the invasion of a murderous nation as a technical right.

WHAT WAS OUR DUTY?

We will now assume, therefore, that this was murder of our citizens. What was our duty? The Constitution as interpreted by the Supreme Court, indeed, our general knowledge of government, would teach us that while we owe service, military and civil, to the Government, the Government owes us as a primary consideration, protection. Government is nothing but a partnership in which we are all members, and we all agree to contribute to the objects of a partnership by service; and then the partnership is to help us in enabling us to enjoy our rights. Therefore, when these citizens were actually deprived of their rights, why, it is very plain that it was the business of the Government to call for reparation in respect to those whose rights had been taken away, and security and an announcement of the policy which would prevent subsequent interference with similar rights of our citizens. Otherwise, if not, then we ought to go out of the government business, because that is the object of government.

Now, Germany announced that she not only justified what she had done, but intended to continue to murder our citizens on the high seas. Our citizens are entitled to the protection of the Government at home and on the high seas, and abroad. Abroad there is some qualification, because they voluntarily submit to another jurisdiction; but on the high seas, on an American vessel, and under an American flag, on that great road of the nations, they are just as much within the jurisdiction and within the protection of the Government at home as if they stood on the shores of New York, or Massachusetts, or New Jersey, and an invasion of their rights on the high seas by a foreign government is just as much an invasion as if Germany had landed a Uhlan regiment on our shores and shot into the homes of American citizens and killed them.

Therefore, if we were to continue business as a government, there was nothing else for us to do — Germany did not leave it open — except to measure swords with her in protection of those rights. If this act had been committed by Venezuela or Costa Rica, if either of those countries had sunk an American ship with a loss of one hundred lives, the President would have promptly sent a message demanding reparation and security against further invasion, and might have sent a warship down to convey the message, just by way

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of suggestion, and every man, woman and child, Senator La Follette, and every pacifist, would have said, "Well done." Well, now, what is the difference between that case and the one we are considering? There is not any principle, but there is this real difference, that Germany is the greatest military power in the world and Venezuela is not, and therefore we are very urgently and strongly in favor of the protection of the rights of American citizens when invaded by a foreign country provided the country is little enough, but when it is a great power — the greatest military power — then the rights are "technical." (Applause.)

Oh, my friends, there was not anything for us to do except to declare war, and a pacifist or any one else who says otherwise or intimates otherwise does not understand. The President has set a precedent by calling them stupid, and, after such an authority, I am willing to say I agree.

Now that brought us into the war, but when we got into the war we found what possibly we ought to have known before — some did know — that the particular cause which brought us in was only a phase of the far greater cause for which the Allies were engaged in fighting. We found ourselves in the beginning ranged with democracies against autocracies. I know that our judicially-minded friend will suggest that England is a monarchy and so is Italy. Yes, that is true, but a democracy is a country in which the people rule, in which the policies of the government are determined by the popular will. The proof of the pudding is in the eating of it. Any one who knows anything about England and Italy cannot say otherwise than that the people rule in these countries, and where that is the case they are democracies. Where that is the case, the question of kings is only a question of taste. As a matter of fact, the King of Italy and the King of Great Britain have not any more to do in determining acute questions of the policies of their respective countries than an ex-President of the United States has! (Applause.)

THE MEANING OF DEMOCRACY

Now, the President has said that we are fighting this war to make the world safe for democracy. That is a truly exact statement. But it has been misconstrued. It does not mean that we are to force democracy on other countries, that we claim to have a patent for our form of government that we are going to drive down the throats of other people. That is not what it means. It only means that the power of a people with a military and foreign policy

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such as that of the Imperial German Empire, is dangerous to the continued and safe existence of smaller and less powerful countries that desire to have democracies and to work out the happiness of their people through that kind of government. That is what it means.

WE MUST UNDERSTAND GERMAN CHARACTER

We cannot understand the issues at stake without understanding the character of the German people. We cannot understand their character without following their training in the last fifty or sixty years. We all have known Germans. We have liked them. When in Germany we have enjoyed seeing them. They are a kindly people; at least they were some years ago when I visited Germany. They are a kindly people who love their homes; they love their families, they love music and they love poetry, of which they have some of the greatest exponents in the world. They conform to authority with a kind of pleasure. They are an intellectual people, they are an earnest people, a little lacking in a sense of humor, but a great people, people capable of great effort.

The truth is, while I have a profound admiration for the English people and the history of England, because having been educated as a lawyer I believe she laid the foundations of true constitutional liberty, nevertheless, I am bound to say that when I went to Europe and traveled in Europe, I would a great deal rather be closed up in a railway carriage with a German than with an Englishman; because the Englishman — I mean the regular Englishman — was constantly engaged in an affirmative effort to convince me that he did not know I was in the carriage, whereas the German was always courteous and friendly and anxious to engage in conversation.

SOME GLANCES AT GERMAN HISTORY

The Germans for a long time were divided into twenty-eight different States, Austria the greatest of them, Prussia the next, and twenty-six others, and every one who longed for an improvement in the world, and an improvement among the Germans, wished for unity among them. There were liberty-loving Germans, and in '48 they rebelled against the divine right of kings, and they had revolutions. They were not successful. They did get a constitutional monarchy for a little while in Prussia, and offered the crown to Frederick William, the great-uncle of the present Emperor, and he said he would not take it, because he got it from God, and did not propose to take it back again out of the mud, showing that the

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divine right of kings came honestly down that line to its present exponent.

A large number of these liberty-loving Germans were driven out of Germany and came to this country, and made one of the most valuable elements of our citizenship here (applause), and when the Civil War came on, loving liberty as they did and hating slavery, they went into the war, enlisted in great numbers, and on every battlefield in that war the blood of our German citizens was shed.

Their descendants and others who have come here since have continued to make a valuable part of our citizenship, and during these three years when we were neutral they have naturally, because of their pride in the success and prosperity of their brethren at home, had a sympathy with Germany and listened to the arguments in her behalf which have been put forth in this war. And now the war between America and Germany has come on, and their allegiance requires them to be loyal, and they are put in a sad position, and one in respect to which we should be considerate of them. But they are loyal, they have enlisted, they have gone into the draft, and contributed to the great patriotic funds; and while they are not vociferous — we could hardly expect them to be so — that they are going to be loyal I have not the slighest doubt (applause), and one of the things we ought to be most thankful for is that very thing. The reason why Germany treated us as she did was because she counted on dissension among our people, growing out of the disloyalty of that very element, and she has been disappointed in that regard as she has been disappointed in so many of those instances where she has attempted to read the motives of other people.

Instead of founding a constitutional monarchy, with representative institutions, and bringing about unity, as those leaders of German thought, Carl Schurz and others, hoped for, there came into the history of Germany a very different individual, Prince von Bismarck, who was the premier of Prussia in 1862. His theory was that he would conquer and unite the German nation by blood and iron, and he developed the army, always a well-controlled body in Prussia, and he made the nation into an army, and an army into the nation, and then he planned the wars upon which he founded the unity of Germany. He became involved in a quarrel with Denmark, and induced Austria to go in with him, and took away Schleswig-Holstein from Denmark; and then when he got it, he found it

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was so easy that he annexed it forcibly to Prussia; and when Austria asked, in a diplomatic way, just what there had been in that war for her, he said there was not anything. And then he got into war with Austria, as he had intended, and in six weeks he wiped her off the map of Germany. Then in that war he annexed forcibly Hanover and Frankfort, and made an offensive and defensive alliance with Württemberg, and Baden, and several other German countries; and then he sat down to wait until that fakir, Napoleon III, in his pirouetting, would bring about an appearance of a war of aggression against Germany, which was exactly what Bismarck was waiting for, and he only had to wait four years for that; and if you will read his memoirs you will see how he brought that about. You will be interested in reading, I am sure, that interview between himself and von Roon and von Moltke. They received a telegram from the Emperor outlining an interview between him and Beneditti, Napoleon's ambassador, and they were thrown into gloom, because the interview was one which seemed so pacific to them that they thought its publication would prevent war; and Bismarck sat down and, without changing the body of the message, changed a few words in it and published it; and then von Moltke said, "Now we will have war." He said, "That telegram, when it came, sounded like a parley. As you have changed it, it sounds like the rattle of a drum." This was stated by Bismarck himself. So, true to his plan, Napoleon declared war, and then, in a short time, Bismarck defeated France and took Alsace-Lorraine and an indemnity of a billion dollars, which the Germans put into the army, and Bismarck crowned a Prussian king Emperor of Germany at Versailles, and he went back to Berlin and sat down as the head of the Empire to digest the pieces of territory he had bitten off in the last three wars.

BISMARCK'S SEEDS OF KULTUR

He was not in favor of world dominion. He wanted to raise Germany to a great power in Europe, and he succeeded. He made fun of the ideal of world dominion, but there was held out to the German people the idea that all the rest of the world would try to get back from them this territory which had been taken, and therefore they must defend themselves, and so they went on and provided greater and greater armies.

They also adopted in their wonderful way, as you gentlemen of science know, the principles of science to the manufacture of everything, and to every field of industry and business. They introduced

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a system which they called *Kultur*, and which brought about a prosperity in competition with the world that attracted the admiration of the world. Their population increased and pressed upon their borders, and with their marvelous successes in the three wars, with their wonderful administration and the demonstration of their efficiency in their prosperity, and with their increase of population, they acquired megalomania, and they learned to think that they were supermen. They believed they had invented *Kultur*, and it was their duty to spread it over the world and enlarge their borders and conquer the world for the purpose of spreading that *Kultur*.

And they soon, by reason of their elevation as a people, associated themselves with God. They regarded themselves as the agents of God. They are a people of an inexorable logic. If they begin with a false premise, as they often do, their confidence in logic is such that they wipe out any fact that is inconsistent with the conclusion reached by that logic. You remember the story of the old German who was in the California gold diggings and met a man out there whom he had seen only recently in New York; and anxious to find out how he had gotten there, he asked: "You came the plains across?" The man replied, "No." "Then you have come the Isthmus over?" "No." "Oh, then you come the Straits of Magellan through?" "No." "Oh, I see, you were seasick coming the Horn around?" The man replied, "No," and then the German's eyes opened and he looked at the man for a minute and he said: "Well, then, you have not arrived!" (Laughter and applause.)

Having established that *Kultur* was necessary for the world, and that they had invented it, they believed that they were the people to spread it; and then, with that inexorable logic, all of these other conclusions followed. The State, the German State, was to spread *Kultur*. It was to do God's work. Therefore, every consideration must yield to the doing of that work. The State was above everything. The State, engaged in this work, could do no wrong. Therefore, these considerations of honor and decency, and the performance of obligation, could play no part. International morality was eliminated. The only sin of a State was weakness; its virtue was power. And that doctrine, or its elements, the idea that Germany was over all, was preached in the schools, in the academies, in the universities, by the great lecturers, by the military writers; and the conviction grew with the people, first, that they must protect and defend themselves and give everything to the

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Army necessary to accomplish that, and, secondly, that they must base their State on force and maintain that force in order that they should spread *Kultur* to the world by domination and conquest. They eliminated, as I say, international morality.

Now, that is the nation and that is the people that we are engaged in fighting. They are obsessed as with insanity, otherwise you cannot explain what you see and read and know. "Why is it," you ask, "we did not know this before we got into the war?" Well, we read excerpts from the lectures and military writings, but we have cranks of our own — I need not mention them — but certainly we do not want to be held responsible for their writings and their statements and their actions, and we assumed that these people, thus speaking among the Germans, belonged to that necessary and conspicuous, but we hope with us unimportant, element. But it was not so in the case of Germany, and you can read now the books that have been prepared impartially showing these sermons and lectures, and showing that these lectures spoke for all the people. Consider, for a moment, that there was a writer who in one of his writings incorporated a prayer like this:

"O Thou who presidest over all, up above, high in the skies, up above the Cherubim and Seraphim — and the Zeppelins —"

Now, that association, if it did not shock your feelings as irreverent, would suggest a humorous view; but to the German mind, with the idea of what the zeppelin was to do in spreading *Kultur*, it was the agency of God; the association between the cherubim and seraphim, which are supposed to be God's agents, with the zeppelins, was entirely proper. They preached sermons on the German God.

WE ARE FIGHTING THE GERMAN PEOPLE

It is the people of Germany we are fighting, with the characteristic they have of subordination to the authority of the Prussian military régime and the Kaiser, and we must not assume they are compelled against their will to do this fighting. They have made too many heroic sacrifices in loyalty to this false idea, and in loyalty to the leadership of the Kaiser, and therefore what the President says must not be misconstrued. What we are trying to do is to separate the people of Germany from the rulers of Germany, but the only way we can separate them from their rulers is by hitting them on the head with a club so that the psychology of the situation will be brought home to them. (Great and prolonged applause.)

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If you look for proof of this position of Germany with reference to the abolition of international morality you can find it in their method of warfare. I do not think it necessary to go into a detailed recital of the awful atrocities that have been proven before you can arrive at a general conclusion as to their violation of every rule of warfare. They bombarded unfortified towns, an act which is forbidden by international law, and the men who bombarded these unfortified towns on the east coast of England were rewarded by being decorated with the Iron Cross.

The Hague Conference provided certain rules with respect to the carrying on of war by means of aircraft, one of which was that belligerents were not to drop explosives from aircraft on undefended towns; and the Germans promptly sent their zeppelins, that were assembled for the purpose of carrying on war, and to which they turned for the purpose of carrying on the war, and they sent these zeppelins to England and slaughtered innocent non-combatants. Of the thousands of victims of the zeppelin raids, possibly not more than fifty soldiers and sailors were hit, and only one or two arsenals, but the great body of the victims is composed of women and children, and old men. The men who navigated the zeppelins in these air raids were also rewarded with Iron Crosses.

THE PATH OF KULTUR

When the Germans entered Belgium they violated their treaties through which they had given their plighted faith for sixty years with the other nations. You would think, when they went into Belgium, under those circumstances, they would treat the people with some consideration, even in spite of their obsession. Did they? No! What they did was to take a district in Belgium and direct their soldiers to pursue the policy of *Schrecklichkeit*, that is, to stand up against a wall the leading citizens and shoot them, as well as the women and children. You ask for proof? Well, read the report of Lord Bryce. He is a lawyer, an able lawyer, and an historian, and he was on the committee with other lawyers and judges, and they took the evidence and dissected it and analyzed it. They rejected all the evidence as to the sporadic brutalities by soldiery which you encounter in every war, and took only the evidence of cases that could not have been committed except by the order of officers, and they showed that this was part of the military policy of Germany in terrorizing the rest of the innocent Belgians by such cruel atrocities in respect to the families of this particular district.

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But the worst thing they have done has been with respect to Armenia. When England brought over the Indian troops to help that small regular army of hers, and they came and made good soldiers, showing they had been well treated, the Germans held up their hands in holy horror and said, "They are sending Mohammedans to fight Christians," all the time having that eminently Christian monarch, the Sultan of Turkey, in alliance with them. And after the alliance was secure, then Turkey proceeded to carry out a purpose that she had partially attempted to carry out years before in ridding herself of Armenian Christians in her empire. She proceeded, with Germany looking on, and with officers of the German Army at hand, through her regular soldiery and her irregular soldiery, to murder eight hundred thousand Armenians because they were Christians. Now, that is an evidence of the false philosophy, the horrid philosophy, that there is no international morality, and that nothing should stand in the way of military success and the advance of the State in the spread of *Kultur*.

That is the kind of enemy we have to fight. That is the psychological state of the German people, and the only way in which we can change it, as I say, is by defeating them. If we defeat them, then they will appreciate the falseness of a philosophy which can only be justified by victory, and then when they are defeated, as we must defeat them, then they will relegate the Kaiser — it will not need any action on our part — they will relegate the Kaiser and the Prussian military régime to the place where they ought to go. (Applause.)

It is a very satisfactory thing to see that the sin of the Germans in this regard has found them out. When the war began, good Christians hesitated about believing in a good God when they saw that so many innocent men could be hurled into a vortex of destruction, agony, suffering and death like this. Now the thing is cleared away, and what we see is that the world has been suffering from a cancer of militarism, and Germany has been responsible for it, and she has led the world on to these great armies, and on her hands is the blood of this awful war — this war with fifteen or twenty times the number of men engaged in it, and with an equally increased amount of suffering and agony, compared with any other war — with 40,000,000 men engaged, 7,000,000 men dead, 6,000,000 men in the hospitals, and 6,000,000 men in prison camps. That is due to Germany. The causes cannot be cut out but by suffering. God works by inexorable laws, and the penalty of sin must be paid.

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This is a German war of aggression as any schoolboy can now see. The White Paper did not show any communications between Germany and Austria during that anxious time, and they have never been disclosed, but we know now that Russia was not prepared, and England not any more prepared than we are today, and France was very lacking in her preparation, and yet we are to believe that these three countries conspired to attack Germany who was ready to the last cannon and the last reservist! Why, that is enough to make a horse laugh. It is true that Germany did not advise the killing of the Crown Prince and his Consort. That is not the way Germany has begun her wars. She gets ready. She plans a war. She gets ready, and then she waits for the opportunity so that it shall seem to be a war of aggression by other powers. That is true in every war she has waged since Prussia has been in power.

GERMANY'S WOEFUL BLUNDERS

So to go back to this sin of Germany's finding her out. She has been perfect in military preparation, she has been perfect in military strategy, but where has she made her blunders? She has made her blunders, and her great blunders, in misreading other peoples, in her diplomacy, and she has made these blunders because she has eliminated from her own soul considerations of morality and motives of good, motives of service and allegiance and unselfishness, and therefore she has eliminated those from her consideration when she goes to judge of what other people will do. And so she made a mistake about Great Britain and her conscience in respect to Belgium. She made a mistake as to the British possessions — I mean those independent dominions. She said, "The tie which binds the dominions to the mother country is very light. There is no reason why they should go in, there is nothing in it for them," and she was indignant and exasperated when she found that her judgment in that regard was wrong. That is because she could not appreciate the filial relation between those countries and Great Britain. She could not appreciate the daughter's loyalty to her mother that had protected her. Is there anything more noble in this world war than the way in which Canada and Australia have responded to the call of the mother country? Canada has sent 420,000 men, and Australia 400,000 men, Australia having a population of five millions and Canada six or seven millions. In proportion, we would have to send an army of seven millions. And then France! Germany said France was decadent, permeated with socialism, no patriotism,

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and deeply affected with frivolity. France was not prepared, but she rallied her legions, and is it not inspiring to think of the fight that she made, knowing that the German military staff was attempting to crush France first! And she stood up, and with that thin line of the British regular army, she hurled back the German hordes at the Marne and saved the world. (Great applause.)

The biggest mistake she has made has been with respect to this country. I remember some of the things the papers said — they said we were a tangoing nation. They said we were too fat to go into the trenches. They had a contempt for us because we had not prepared for war. They assumed our citizenship of German origin would prevent the war, and political considerations would divide the people in that regard. They were also obsessed with the idea that they could end the war with this murderous weapon, this weapon they could not use except by accompanying its use with the murder of neutral people. So they went in.

WHAT WE ARE FIGHTING FOR

Now, ten, fifteen or twenty years hence, when our grandchildren go to their fathers, after having read a history of this war, they will say, "Papa, why in the name of common sense did Germany force the United States into this war?" And papa will have a hard time to tell, unless he goes into all of the circumstances and treats the subject from a psychological standpoint, because the boy will say — any child would say — "Why, they had been fighting this war for three years, exhausting as no other war had been before, so that they were all not exhausted, but nearly so, and at that time they deliberately forced into the war against them that gigantic young nation that could furnish what is absolutely necessary, and what must determine victory in the war: more food, more money, more fighting men than any nation in the world."

Now, that is what they have done, and nothing can explain it except the obsession that I have referred to — their failure to see things in other people, because they have eliminated from their own consideration those moral motives. Now, what are we going to do about it? I have said, potentially we are the greatest power in the world. We are a potential military power, and we have got to make that thing which is potential actual, and that is no mean job. We have before us a war of two, three or four years. We have got to raise an army of five million or seven million, or possibly more. It is man power that is going to win this war. Russia has become a

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pulpy mass, and it has got to work out its own salvation. There is one feature about that situation, and that is that the Germans will not know any more about what is going to happen in Russia than we do, but it is going to enable the Germans to bring back, doubtless, many of her divisions to the western front; and we must fight the war out on the western front, and it may be that the western front will reach from the North Sea to the Adriatic. We have got to furnish to our Allies not only food, not only money, but we have got to furnish them the man power that will give a predominance that will win this war. We have got to wear them out, it may be by attrition, as Grant wore Lee out, but we have got to do it, because civilization depends upon it, because our own independence depends upon it. The war is not in our souls yet, not as it will be when our boys are shot down, and when we consult the casualty lists to see whether those dear to us have suffered. One of the great satisfactions is that when we are in it, when we meet disaster, as we are going to meet disaster, and we find there have been blunders, as there will be blunders, the American people are so constituted, with their inherited traits, that those disasters and blunders and defeats and humiliations will only make us stronger to carry out the struggle that is essential to liberty and Christian civilization. (Loud applause.)

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No. 1604

ACTIVITIES OF THE SOCIETY FOR 1917[1]

By Ira N. Hollis, Worcester, Mass.
President of the Society

THE past year has been of such vital influence on the future of our profession, as well as of our country, that I desire to lay before the members a brief report of our activities and our possibilities for the future. This is not intended to replace the detailed statement of business transacted during the year and of the varied committee activities usually contained in the annual report of the Council, but it seems wise, on the whole, to bring the Society up to date in a general way. The reports of Committees, of course, are in print for this session.

The American Society of Mechanical Engineers was organized in 1880 for the purpose of promoting engineering science in every way. At that time mechanical engineering was hardly recognized as a profession. It was never distinctly a part of civil engineering, but grew out of the modern demand for men to take their places in industries and manufacturing. The few who practised mechanical engineering in the early days were essentially designers of machinery or investigators, like Leavitt and Thurston. Consequently, for many years the papers of the Society were confined to technical and educational subjects for the benefit of its members, and through them for the benefit of the public. Our Society is fundamentally educational, and that must always be its chief function if it is to continue as a society for the advancement of applied science. Through the influence of the engineering colleges and the rapid advance in manufacturing, the profession has changed, and the mechanical engineer is no longer tied exclusively to technical questions. The old guard has given place to consulting engineers who deal with industrial and power questions on a large scale, and with the management of great

[1] Constituting the Report of the Council for 1917.

Presented at the Business Meeting of the Annual Meeting, December 1917, of The American Society of Mechanical Engineers.

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industries, leaving the details of design and construction to thousands of young engineers who have been absorbed by manufacturing and operating companies. We must recognize also that mechanical engineers have by training and experience become leaders in business, especially in business connected with manufacturing.

SOCIETY HAS RESPONDED TO CHANGES IN CONDITIONS

To this rapid change during the past generation, the Society, while holding to its original purpose of advancing engineering through the discussion of scientific papers, has responded in proportion to the demands of the members, to the vision of its officers, and to the needs of the country, exactly as the constitution of the United States and the governments of our commonwealths have been made to fit a growing population and a larger understanding of coöperation. While there have been differences of opinion on all kinds of subjects (and no society is in a healthy state unless there are differences of opinion), and while we may have missed some opportunities for usefulness, on the whole our Society has not failed of its duty to the country. We have never been leaders of propaganda on political and social reforms, and we cannot be without running the risk of losing our character as a scientific organization or splitting up into cliques that would destroy one another. On the other hand, our annual meetings have provided a forum for discussing and assisting great advances in industrial organization and in the art of manufacturing. It is here, for instance, that papers have been presented on a wide range of subjects, extending from test codes for power and the Boiler Code for the construction of safe boilers, to standardization, testing of materials and scientific management.

The attitude of the Society, as a whole, is well indicated by the character of the men who have been elected to the governing boards. They have invariably been friendly to the coöperation of the engineers with the public in the proper development of our material resources, and have been both sympathetic and responsive to the desires of the members. In going about the country during the past year, which I have done systematically as part of my duty while president of this Society, I have never heard a word of complaint against the Council or their methods, excepting in a very few cases, unhappily open to suspicion of an unbalanced judgment. Our Society does not stand for that.

We must remember that in a national society covering the vast

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range of territory we have in America, there are many scattered groups that seldom come in touch with one another. The general headquarters must necessarily be in some one locality, and New York was long ago chosen as perhaps nearer the center of the enterprise of the world than any other city. The Atlantic Ocean is nothing now, and New York places us in almost the center of gravity of manufacture. Nevertheless, a group of our engineers in San Francisco, for instance, is far removed, and they seem sometimes as if they were not genuinely a part of the national society; but it is a mistake to feel any isolation. Every member of our Society ought to know that he is very likely to get out of the Society what he puts into it, and any effort toward improving the Society or toward educating its members through scientific papers or by contribution on broad, general questions is quickly recognized.

During recent years the Sections of the Society have been regularly organized, and the Sections Committee has been established to encourage activities within every Section. There is a session at this annual meeting that will bring their representatives together for a concerted study of how to make the Society reach out even more effectively to every one of its members.

DEMOCRACY OF THE SOCIETY

The democracy of the Society cannot successfully be assailed. It has been suggested that the president has it within his power to continue his own influence by appointing his own kind of a nominating committee for the officers to succeed him. To use the language of the street, this is absolute rot. It has not been the custom for the president or the officers to influence the choice of the new Council members, and almost invariably the whole Society has been solicited for suggestions. The consistent tendency is toward a greater participation of the members, and therefore toward greater democracy as we learn how to be wisely democratic. This Society is not an assemblage of the "bandar log," ready to chatter over the latest fad, but a union of men sincerely interested in benefiting their country through science. That we must always remember in scanning proposed reforms.

Furthermore, the Society is in the hands of its members and not in the hands of a few corporations. We must not permit ourselves to go to an extreme because corporations have sinned in the past, and because they are going to sin in the future. The directors

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of all corporations are human as our directors are human, and they will make mistakes over and over again, and we will help to correct them over and over again, but our Society is not a creature of any public-service corporation, and it never has been. It stands for truth in science, and it ought to help the truth in the social life of the country. Its purpose, however, is the truth in science and not a partisan conception of the truth.

One has only to take a list of the officers who have served our Society to find that all aspects of modern industrial life have been wisely represented. There is no earthly reason why our Council should be organized as the enemy of the men who conduct our great affairs, nor should it be organized as their special advocate. It is organized for the truth and nothing but the truth. Consequently, we should not as a Society permit ourselves to be led away by catchwords, nor should we permit ourselves to be fooled by a list of our mistakes. We know that no human institution ever can be freed from imperfection and mistakes will always be made, and in our country, thank God, will always be corrected.

THE SOCIETY'S PUBLIC RELATIONS

It is sometimes difficult to determine how far the Society ought to go in its public relations. At this time, while we are at war, there is no limit to the sacrifice that ought to be made to the common good, and to the work that ought to be done by the members individually and the Society as a whole toward the success of our country in war. There is a difference, however, between individual activity and collective activity. This is the time when the individual can offer himself, and when the Society can best serve as simply the intermediary for assisting the individual to serve well. That we have systematically tried to do. At the present date, fully ten per cent of our membership is in service. In ordinary times of peace it is sometimes a question how far we ought to depart from the orderly discussion of technical and scientific papers. We have the right by our charter at any time to enter into legislative questions or into any of the great economic questions before the country. We have no right to take part in partisan politics, either from the point of view of the legality of our charter or from the point of view of policy with regard to the future development of our Society.

We have taken part in many things of public interest and in many things involving the public. For instance, in our Boiler Code we have affected legislation in many of the states and municipalities.

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In our Committee on Standardization we have done a great deal of good work, culminating finally in a general Standardization Committee to represent many societies so that we may work together. In our Power Test Codes we have had a very wide influence throughout this country on the development and design of power stations. It is not necessary here to go into the details of our activity, but I think it is easy to make evident the fact that our Society has always been one of public relations.

In connection with public relations there are sometimes great differences of view on the part of engineers generally. I have been disposed to ask the question, "Is it right that any one society of engineers should take a stand on any public question that affects all engineers without a full discussion of the subject with other engineering societies?" The engineers have only slowly come to a proper representation of themselves before the public. If we are to have our legitimate influence over public affairs we all must act together. It is only common sense, then, at least to thrash out subjects before a senate of the engineering societies, or what we have called an Engineering Council. To that end the American Society of Civil Engineers, the American Institute of Mining Engineers, The American Society of Mechanical Engineers and the American Institute of Electrical Engineers have joined together to form the Council for considering all matters referred to them by a single society or by our Government. It is the only method of taking up public affairs. Consequently, we may well ask ourselves the question at the present time, "How far ought any single society to act alone?"

OUR ACTIVITIES FOR THE YEAR

I am glad to call attention to some of the details of our activities during the year. The election of Major-General George W. Goethals as an honorary member adds one more to the long list of distinguished men who have had membership in our Society. This kind of membership has never been refused, and it is rightly regarded by us as the highest acknowledgment we can make to great service in engineering. The regular membership of the Society has been steadily increasing, mainly due to the efforts of the Increase of Membership Committee and to the good standing of the Society as a useful aid to engineers who are going into mechanical engineering.

The Local Sections all over the country form a very important adjunct in this regard, and the administration has been wise in per-

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mitting them to invite non-members of the Society to all meetings. The coöperation of these Local Sections is encouraged in every way, in order that they may have touch with the sections and branches of other societies. Every engineer in the United States ought to have membership in a national society, and also some relation to the local sections or local societies. It is the only method by which we can be drawn together as engineers.

Attention should be called to the number of Local Sections in the country. There are twenty-two, one of which is a state Section, with five branches. This is a very interesting departure from former practice, and promises rich developments in the future. Every state could have its organization of engineers, with branches in the principal cities. Our Society would accomplish much good by fostering that idea.

It is not necessary for me to refer here to the Cincinnati Meeting beyond the remark that it will go down in the history of our Society as one of the great meetings where Cincinnati outdid herself in the entertainment of her visitors. We met with the Machine Tool Builders' Association, and the meetings are rightly emphasized in the report submitted by the Council.

The Student Branches hold out possibilities for excellent coöperation between the colleges and our Society. This has not been developed as fully as possible, and we should, by visits to the colleges, by coöperation with the Society for the Promotion of Engineering Education, and by a better acquaintance with the faculties, lend all possible aid toward the better education of men who are going to come into the profession of engineering. We ought to have some systematic part in education.

OUR BIG WORK OF CLASSIFYING ENGINEERS

There has never been a more important year to our Society than the past, during which war has been declared against a strong combination of nations and the country has been called upon to form and equip a large army. We have all been eager to serve in some way. At the same time, the place for service has not always been self-evident. In the inevitable confusion, no system was adopted by the War Department or by the Navy Department in the organization of men for commissions in either service. Orders were issued and recalled for a great variety of things, so that even at this time an engineer is puzzled where to apply. Our Society has done something to help in this situation, but not all that might have

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been accomplished under more favorable conditions. We have joined with other societies in the Engineering Council to form a committee for tabulating the members of our Society as to their attainments, their previous experience and their willingness to serve. This committee, with George J. Foran as chairman, has done yeoman work in devising an admirable system for obtaining the information required. Inasmuch as the tabulation is a long-time piece of business, they have quickly listed several thousand names from the various societies as specialists along various lines. The names have been submitted to the departments of the Government and to the industries generally as they have been requested.

It has been very puzzling to know just how far the Society could go, as the responsibility for the selection of men and for the suggestion of the needs of the service must rest with the commissioned officers of the army and navy, under orders of the President. Wherever the Society has been requested to lend its aid in the procurement of men for commissions for special service in civilian lines, or for the formation of regiments, it has gladly responded, always supplying more names than were needed in order to be absolutely fair with all members. The members of the office force, from the secretary down, have had a full realizing sense of the obligations on the part of all of us to serve in every way and to help in the formation of an army so that our country might be most speedily prepared.

The tabulation of engineers, if carried through all the societies, national and local, will be a directory of American engineers. It should be catalogued and cross-catalogued for names and branches of the profession. There should be at least two copies, one filed in New York and one filed with the local society in which a member is resident. Such a directory can be made useful in the readjustments of our industries in peace after this war is over and in the better organization for the conduct of business. The United States never has been able to coöperate well in industries. In fact, such coöperation has been discouraged under the idea that it might in some way defeat competition, which is said to be the life of trade. Nevertheless coöperation ultimately means exchange of information, and a resulting reduction in the cost of everything that we make.

There is another aspect of this, so far as the individual societies are concerned. Every society, and ultimately the Engineering Council, ought to provide some method to assist the younger members. An employment office is a perfectly legitimate part of our activity, and, as a matter of fact, one has been carried on by The American

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Society of Mechanical Engineers for many years, to the great satisfaction of many men who have found positions through the office here in New York.

THE SOCIETY AND STANDARDIZATION

Reference is often made to standardization, in which our Society has taken a very active part for years past. The committee appointed to act with other committees will assist in placing the development of commercial standards among the men best able to pass upon them. The example of the Society of Automotive Engineers should stand as an inspiration to us toward the establishment of all kinds of commercial standards to facilitate manufacture; although it was much easier for that society to promote standardization among automotive manufacturers, because it was one of the methods by which they could get their orders filled. Where the steel industries were called upon to provide hundreds of different kinds of steel, many of them for the same purpose, and hundreds of different dimensions, where comparatively few would have sufficed, it was imperative that the manufacturers should get together, and they have done this effectively. Our Society stands at a disadvantage with respect to standards, as it has nothing of the commercial about it, and no method of forcing upon any manufacturer its findings with regard to standards. We depend, then, upon the slow process of persuasion.

One of the aspects of standardization appears in the controversy over the metric system. There is much difference of opinion about the wisdom of replacing the English units with the French units. Many sincere men believe that we ought not to make any change. Others believe as strongly that we ought. It would be wiser, on the whole, for the Society to maintain this place as a forum and to keep out of this controversy as a society until the way seems more clear. That will not prevent any member of the Society or any group of members from writing on the subject, under the encouragement and for the benefit of our membership and for the benefit of the country.

One of the industries that has grown with remarkable rapidity in the past few years is that pertaining to gages of all kinds for the manufacturing of munitions and other supplies. Gages are as necessary in time of peace as they are in time of war, but not in such great quantities. The mistake made by the Government has been the neglect to accumulate a large stock of gages. Last spring in Cincinnati very strong representations were made to the depart-

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ments in favor of a central locality for the comparison of gages and for certifications as to their correctness. Congress appropriated a large sum and authorized the Bureau of Standards to take on, as part of its function, the comparison and certification of commercial gages of all kinds. This is a radical departure, and it should lead to a great improvement of manufacture in many respects. Our Society has appointed a committee to serve as consulting engineers for the Bureau of Standards in connection with this new departure. We as a society are prepared to assist the Bureau, which is doing such fine work for the country.

Another question which has come up during the year grows out of a request on the part of the Bureau of Mines and the Fuel Administration to assist in fuel conservation. The whole subject was referred to the Engineering Council, and through the Council consulting engineers have been appointed for the Bureau of Mines to advise in regard to the technical matters connected with fuel conservation and with the use of fuel. A committee was also appointed at the invitation of the United States Chamber of Commerce to serve with a general committee on the whole general question of fuel. During the year, committees of our Society were also appointed to assist the Bureau of Mines in various ways, but inasmuch as the war has seriously interrupted the development of the new laboratory in Pittsburgh, these committees have been inactive. Their time will come, however, and they will be able to do for our Government the work that this Society is glad to give.

OUR VARIED BUT VITAL ACTIVITIES

It is not necessary to refer at any length to the service of the members of our Society in the army and navy. At this time, John H. Barr, W. B. Gregory and Max Toltz of the Council hold commissions as majors in the army, and are serving in important positions. The Society itself has sent so many to the colors that we would find it difficult to tabulate them here. In fact, it is doubtful if we shall have a complete list until after this war is over. Those serving for the Naval Consulting Board and in other capacities are helping splendidly, even though they are occupying positions less spectacular than those on the lines.

The year has seen an innovation in connection with the meetings of the Council. We held in November a meeting in Chicago, in order to test the value of meetings outside of New York. It seems only right that the larger Local Sections at least should have

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an opportunity to meet all the members of our Council; not only for their own satisfaction, but also to inform them about the needs of the localities. It is hoped that this plan of meeting in the different large cities from time to time may be carried out in the future. The meeting in Chicago was a great success, as it brought together a very large number of the mechanical engineers. The visiting of the various Local Sections by the Local Sections Committee is also an important move in making our members better acquainted with one another and it is quite certain that the journey made by the Committee this fall was useful.

One of the valuable elements of the work in the Engineering Building relates to the Library, in which all the societies share. There is no respect in which we can make our distant members feel more interested and benefited than in giving them access to the library by correspondence. Any member ought to feel free to write for a synopsis of any article or for a search, at a minimum cost, and the library should have duplicates, in order that books might be loaned. They could be sent by express to different parts of the country for use, to be returned within a specified time. This is the practice in many other libraries and it could be made very useful here.

The Power Test Committee, under Mr. Barrus, has long been giving its attention to the details of all kinds of power tests. The usefulness of their work in the past has been amply proven, and every effort should be made to assist them in perfecting the code. A hearing and a discussion in our building has been encouraged. Its results should be bountifully fruitful. It must be remembered, however, that no one group of men will know all power tests. Consequently, it seems advisable to invite sub-committees to work out the different kinds of tests. This has been planned and it is hoped that by advisory boards and sub-committees we may improve our test code.

This Society and the whole engineering world owe a debt of gratitude to the members of the Boiler Code Committee, whose patient work has benefited us so much. The Code is operative in many cities and eventually it will probably apply throughout the whole of the United States, thus promoting the safety and welfare of many men.

I call attention to the Secretary's detailed summary of activities, which will be issued later, for a fuller statement in tabulated form of all that we have done. The development of THE JOURNAL as

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a means of placing important papers most quickly into the hands of readers is extremely gratifying, and under the direction of the Publication Committee it has disclosed many unexpected possibilities. The question may well be asked why we continue to publish the TRANSACTIONS as a separate octavo volume when the whole of our activities may be printed in THE JOURNAL. No foreign society ever publishes duplicate transactions. If some way could be found of making THE JOURNAL a mouthpiece for all societies, the bulky volume issued annually for each society would have a natural place; otherwise, the extra twenty thousand dollars spent by our Society might be saved to make THE JOURNAL better.

I cannot close this brief report without a cordial acknowledgment of the politeness and consideration that I have received from Sections and members of the Society. It has been a pleasure instead of a task to serve them as president. The patience and kindness of the office force could not have been surpassed, and the untiring zeal of our Secretary, Mr. Rice, for the good of the Society and of our country deserves the warmest acknowledgment from members and their officers.

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No. 1605

THE RELATION OF ENGINEERING TO INDUSTRIAL MANAGEMENT

By Dexter S. Kimball, Ithaca, N. Y.
Member of the Society

WE have all become somewhat accustomed to seeing the engineer called upon to perform new and strange duties, but few of us were prepared, I believe, to see an engineer called upon to undertake the greatest piece of constructive economics ever attempted. I refer to the work of Mr. Hoover, for Mr. Hoover is by training and practical experience a mining engineer. Yet this somewhat startling event is in full keeping with the trend of modern industry. Every day sees the duties and responsibilities of the engineer widened and it is difficult to see where the end will be. The engineer from the first has had a difficult time trying to define just what his field of activity is. This is necessarily so in any civilized community where the life of the people rests upon mechanical contrivances. Engineering, and mechanical engineering in particular, is an integral part of everyday life and necessarily assumes fresh aspects as the complexity of modern life increases. It will be increasingly difficult to set its limits and boundaries.

These matters have long been a cause for work and worry on the part of teachers in technical schools. The original conception of these institutions was to train men to design, build and operate machines within a narrowly defined field. Fifty years ago the term "mechanical engineer" conveyed a fairly distinct definition of activity; today it is almost meaningless.

The closely prescribed curriculum of the early engineering schools of years ago succeeded well in sending out men who in time made a place for themselves in the engineering field. But the men who passed through these schools were far from satisfied with the training they thus received. Their complaint, however, has not concerned the technical studies imposed upon them alone, but has em-

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bodied a demand for broader training in harmony with changing industrial conditions. The variety and scope of these demands have been great and have changed with the changing industrial field, but the demand for instruction in the subjects that pertain to industrial management has been constant, insistent and has grown steadily. Today there is not a first-class technical school in this country that is not recognizing this demand. The technical schools of today are not places where engineers, as defined by this term originally, are educated, but they are schools that prepare men, and women also, for industrial life in an amazingly broad manner. An examination of the list of graduates of any good technical school will show that twenty-five per cent of them remain in engineering pursuits in a narrow sense, the remainder going into a very wide variety of industrial pursuits. A very large and increasing proportion are found on the management side of industry.

It may be argued, of course, that while engineering may be a part of management, management is not part of engineering. And it may be truthfully stated that the engineer has been drawn over into management more because of his peculiar method of attacking problems than because of his technical or commercial knowledge; and that for this reason engineering colleges may well neglect these broader subjects and confine themselves to the time-honored engineering studies. While this may all be true theoretically, the fact remains that the industrial field is demanding men from the engineering schools who are well grounded in engineering and, in addition, know something of management. Hence we find such subjects as economics, psychology, logic, public speaking, and similar studies included in engineering curricula, and they appear no more or no less strange there than does an engineer as a food administrator.

Now what is true of the engineering schools is equally true of The American Society of Mechanical Engineers. The engineering colleges have lagged behind the industrial field in these matters, and the engineering societies in turn have lagged behind the colleges. It is interesting and instructive to read what the founders had in mind when the Society was organized in 1880. Dr. Robert H. Thurston, the first President, in his inaugural address states these objects to be "the promotion of the arts and sciences connected with engineering and mechanical construction." And the chairman of the preliminary meeting, Mr. A. L. Holley, enumerates in some detail the several branches of engineering contemplated as follows: metallurgy, railway engineering, machine-shop work, rolling mills,

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structural work, national defenses, shipbuilding, agricultural machinery and textile machinery, and concerning the latter he states, "The public would deem it quite outside of mechanical engineering." It is on this analysis as a basis that the first list of those eligible to election was made up, namely, mechanical engineers, civil engineers, military engineers, mining and metallurgical engineers and architects. And after reviewing the field, which to us now seems so restricted, Mr. Holley remarks, "I confess that in thinking over the range of mechanical engineering with reference to our proposed society I was astonished at its magnitude. I had never realized it before."

Only once in the statements made by the founders concerning the objects of the Society do we see a vision of what the future held for the Society when Dr. Thurston said, "Its province will lie no less in the field of social economy than in that which has reference only to the individual needs of its members." This germ of thought has always remained in the Society and found its most widely known expression in Frederick W. Taylor's classic paper on Shop Management. But though this remarkable paper was presented to the world through the Society, comparatively little has been done by the Society to further this important line of thought. There is not even at this time a sub-committee on this field of work.

Ten years ago Prof. F. R. Hutton in his presidential address made an exhaustive review of the aims and activities of the Society which is well worth reading. He found that about fifty per cent of the membership at that time was classifiable under the headings "manufacturer," "shop executive" and "local manager." Yet the TRANSACTIONS for that year do not contain a single paper on industrial administration, though Taylor's masterpiece had been published three years before. An examination of any page of the Year Book will show that this relation has not changed and that the Society is far from being, strictly speaking, an engineering society, but that it represents industry in a very comprehensive and broad manner. That this view is recognized is clearly shown by the names of a few papers in the TRANSACTIONS for 1916, as for instance, How Does Industrial Valuation Differ from Public-Utility Valuation? or Graphical Control on the Exception Principle for Executives.

What is true of the relation of mechanical engineering to management is also true of many other fields. Is the problem of electric welding one for the mechanical engineer or does it belong to the field of electrical engineering? Where shall we place oxy-acetylene

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welding or the thermit process? Accident prevention is certainly within the range of the Society's activity, so far as the mechanical features are concerned, but how far shall we interest ourselves in employers' compensation acts and the legislation that lies back of this important movement? Shall we discuss it as a problem in mechanical engineering or shall we also include the humane features of the problem? At the present moment a strong movement is on foot to interest engineers in the important problem of Americanization, and engineering schools are being urged to pay special attention to this matter. The subject is timely and important and no single class of men can do so much to promote it as the engineers. The problem is closely connected with industrial management; shall it become, therefore, a problem for engineers and engineering societies?

These intricate relations come before the Society largely through the work of the Committee on Meetings in passing upon papers to be presented before the Society. As would be expected from the foregoing, the papers offered cover a very wide range. The majority are well within the range of the field of engineering as commonly understood; a number are in the field of industrial management or in other fields equally removed from engineering in a strict sense. From this latter class the Committee on Meetings selects those that, in its opinion, can properly be presented, though even with this class of paper the Committee is not always unanimously agreed. Lastly, there are a number of papers presented that in the opinion of the Committee are so far removed from engineering as to make their presentation questionable, though they are sometimes valuable papers. The tendency, therefore, is rather to discourage papers which treat of matters on the "fringe" of engineering. I sometimes wonder if Taylor's paper on Shop Management, had it been presented by some one less known and under some other title, would have been accepted. It is fairly certain, moreover, that if more encouragement were given to papers of this broader character the Meetings Committee would be in receipt of many more of them, and it is not too much to expect that it would, in time, receive papers that would be as great in their field as is Taylor's classic. It is entirely a matter of how far the Society wishes to recognize its non-technical membership. It is noteworthy that the best collection of papers on the problem of employment of which I am aware is not found in the literature of engineering or industrial management, but is in the *Annals* of the American Academy of Political and Social Science. I wonder how many employers have seen them. Quite a

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number of these papers were written by engineers and industrial executives. It is also to be noted that within the last year at least two societies have been started to carry out work that, in my opinion, belongs to this Society.

I believe the time has come, therefore, when the Society should redefine its aims and objects, and I would like to see an inquiry made into the aims and objects of our Society with a view to finding out how well the literature of the Society is meeting the wants of our membership. Or, putting it another way, if we are satisfied with the literature I think we should try to obtain a membership that is in harmony with it, a condition which, in my opinion, does not exist at present. And I should like to see such an inquiry made in a statesmanlike manner without reference to persons or groups of persons, but with the sole object of finding out what is best for the Society and what will insure to it an enduring future.

There will never be a better or more opportune time to consider this subject. Every loyal American is now asking himself what are his duties and responsibilities. Every technical school is facing a reorientation of its purposes and aims. As a nation we are facing a period of self-analysis that may result in changing some of our fundamental policies. I am not so sure, for instance, that we shall continue to be a "refuge for the oppressed of the earth" unless we are quite sure that the aforesaid oppressed are really in pursuit of the liberty and happiness that we all hold so dear. Americanization may indeed be a part of the work of all organized bodies that are interested in the existence of the Republic. If we have not at this moment a clear vision of whither we are tending, now is the time of all times to take stock of ourselves and to redirect our course, whether this course is in conformity with time-honored definitions or not. Change is not necessarily synonymous with progress, but there is no progress without change. No one can doubt that the scientist and the engineer are to be the most important industrial figures of the near future. If we are faithful to our duties we shall be of greater importance politically and socially, but to accomplish this we must broaden our vision and get about our business, which is the industrial organization of our country.

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No. 1606

A COMMERCIAL ANALYSIS OF THE SMALL-TURBINE SITUATION

By W. J. A. London, Springfield, Mass.
Member of the Society

This paper is devoted to a commercial analysis of the four types of small steam turbines now on the market and used for the driving of auxiliary machinery, dealing principally with non-condensing units.

In these, high thermal efficiency is in many cases unnecessary on account of economic utilization of the exhaust steam, and as economy bears a definite relation to first cost, a highly efficient machine is often a mistaken investment. Moreover, operating conditions are generally such that the designer must sacrifice considerations of efficiency if they interfere in any measure with simplicity and durability.

The theoretical design, according to the author, presents no difficulties, but the mechanical design is what determines success or absolute failure; and some of the problems involved and the methods that have been employed in solving them successfully are indicated.

The average specification calls for very rigid guarantees as to steam consumption, speed regulation and load requirements that, in the opinion of the author, are in most cases unnecessarily severe and merely tend to increase the cost of installation. After an extended survey of the situation, he has been led to formulate a Code of Practice, given in an appendix to the paper. The adoption of this code would, he believes, bring about a reduction in selling prices, eliminate many of the unpleasant experiences which now often arise between manufacturers and customers, and thereby increase the popularity of the turbine-driven unit.

EIGHT years ago the Society was presented with a very valuable and complete paper[1] by Mr. George A. Orrok, Mem. Am.Soc.M.E., on the small-turbine situation at that time. A great deal of further development has naturally taken place since then, changed operating conditions calling for considerable modifications in design. Increased competition and a broader conception of the possibilities and limitations of various types have resulted in a gradual elimination of certain principles of operation and a general trend toward the adoption of one common type.

[1] Small Steam Turbines, George A. Orrok, Trans.Am.Soc.M.E., vol. 31 (1909), p. 263.

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2 We have seen during the last six or seven years a very marked tendency toward standardization of type in the larger machines. Practically every builder has resorted to the *composite* type, i.e., multi-velocity staging in the high-pressure element and pressure staging at the low-pressure end. Even such a zealous advocate of the *pure* type as Parsons himself has now been converted to the advantages of, and is building, the composite type of machine.

3 The same condition exists in the field of small machines, and it is interesting to review the various designs as mentioned by Mr. Orrok in 1909 and to see which have survived the test of time and experience; and among the ones that have survived to note the modifications that have been made to suit present practice.

4 In the order given we find: (1) *De Laval*, (2) *Terry*, (3) *Sturtevant*, (4) *Bliss*, (5) *Dake*, (6) *Curtis*, (7) *Kerr*, (8) *Wilkinson*. These may be conveniently classed in general types, as follows: (*a*) *De Laval;* (*b*) *Terry, Sturtevant* and *Bliss;* (*c*) *Dake;* (*d*) *Curtis;* (*e*) *Kerr;* (*f*) *Wilkinson*.

5 The Bliss, Dake and Wilkinson are either no longer on the market or are not seriously competitive; Sturtevant and Kerr still manufacture their original types only, with minor modifications; but De Laval and Terry have both recently developed machines on the Curtis principle. As these latter firms are two of the largest manufacturers of small turbines today, it would appear that there are sound reasons why they should depart from their original designs, and this fact is indicative of the general trend towards standardization mentioned above.

6 Since Mr. Orrok's paper, five new machines have appeared on the market. They are the Westinghouse, the Allis-Chalmers and Wait, reviving the Wilkinson principle as described by Mr. Orrok; the Lee, manufactured by the Witton Co. of New London, Conn., which is a modified Terry machine; the Alberger, an unmodified Curtis, — in fact, manufactured under license from the General Electric Co. and hardly to be considered as a separate machine; the "Steam Motor," also a Curtis type; and the Moore, a modification of the Kerr machine. We have, therefore, at the present time the following types to consider: (1) The *Terry*, which includes the Sturtevant and Lee machines; (2) the *Westinghouse*, which includes the Allis-Chalmers and Wait machines; (3) the *Curtis*, which includes the machines manufactured by the General Electric Co., Terry, De Laval, Alberger, The Steam Motors Co., and Moore; and (4)

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the *Kerr* type, manufactured by the Kerr Turbine Co. and the Moore Co.

7 The machines in the first three groups employ velocity staging, and in small machines are for the most part single-stage and will be considered as such for comparative purposes. Some of the designs are of course arranged for "staging," to improve the economy, but as this does not affect our considerations when comparing the relative merits of the general types, all machines in this class will be assumed to be of the single-stage type. The Kerr machine, primarily based on the pressure-staging principle, must be considered separately as a multi-stage machine.

8 As the title indicates, this paper is devoted to a purely commercial analysis of the various designs and the situation in general, and will deal particularly with non-condensing units. The thermodynamic features will be barely touched upon, except in cases where they have a direct bearing on the commercial aspect.

9 There are three distinct aspects to this situation, namely:

a The type to be employed that will give the necessary competitive efficiency with the lowest shop cost to the manufacturer, together with a design that will give satisfaction to the customer after installation

b The aspect from the salesman's and customer's point of view. This governs the rating or maximum output of the machine, standardization of specifications, etc., as well as the proper appreciation of efficiency, with its relation to first cost. This latter phase is perhaps better explained by stating that in many instances water-rate efficiency can be economically sacrificed in favor of first cost, and vice versa

c The policy of the manufacturer who builds one part of the apparatus (such as the turbine) toward the manufacturer of the other end (such as the pump), and their united policy toward the customer.

CONSIDERATION OF TYPE FOR EFFICIENCY

10 As just mentioned, we have now four distinctive types, three employing the multi-velocity principle and one still retaining the pressure-staging principle. The general action of the steam in these various types is so well known that no explanation here is necessary.

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11 Let us first consider the possible capacity of frame in each particular type with a given wheel diameter. This controls the weight per horsepower, one of the most important features of design from a manufacturer's standpoint.

12 This phase can be simply analyzed by a casual study of limiting dimensions. The output will be considered in terms of jet-outlet area. The machines under present considerations are single-stage, so that a comparison on this basis eliminates any necessity for considering the operating conditions.

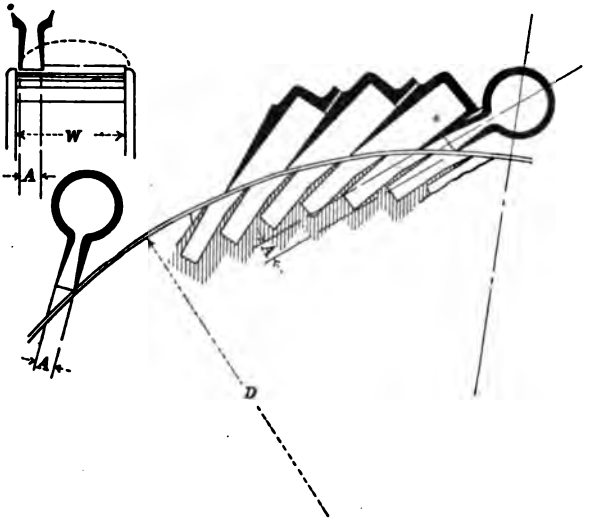

FIG. 1 TERRY-TYPE TURBINE

13 *The Terry Type* (Fig. 1). The width of the wheel, W, bears a given relation to the diameter. The jet width necessarily bears a certain relation to the width of the wheel. The jet being square. each jet has a certain area dependent upon the diameter of the wheel. The reversing chambers must necessarily cover a certain arc of the periphery, and there must be a certain space left for free exhaust, so that the pitch of the jets is thereby limited.

14 Terry has found that the best commercial results are obtained with the following approximate proportions (Fig. 1):

Let D = outside diameter of wheel, in.
W = width of bucket, in.
A = side outlet of jet, in.
C = capacity of machine, sq. in. of outlet area.

Then $A = W/5$; $W = D/9$; therefore $A = D/45$ . . . . . [1]

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15 It is found that the maximum number of jets that can be placed around the circumference to allow for an unrestricted exhaust is eight. As the ratio of jet to wheel remains practically uniform throughout, this rule holds good for any diameter of wheel. Therefore,

$$C = 8 \times \left(\frac{D}{45}\right)^2$$

or

$$C = 0.00395\, D^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots [2]$$

16 With an initial pressure anywhere between 100 and 200 lb. per sq. in., and atmospheric exhaust, the following formula gives a close approximation of the maximum capacity in terms of total steam per hour and wheel diameter:

$$Q = 0.00395\, D^2 \times (4.6\, P + 2160) \ldots\ldots\ldots\ldots [3]$$

where Q = steam per hour, lb.
P = initial steam pressure, gage.

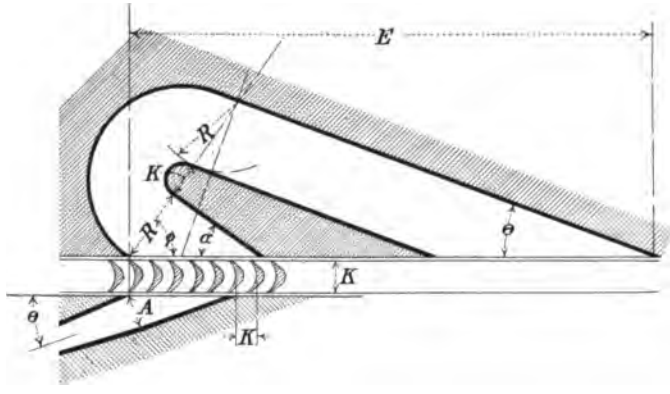

FIG. 2 WESTINGHOUSE-TYPE TURBINE

17 *The Westinghouse Type* (Fig. 2). In this design considerably more leeway is available than in the Terry, inasmuch as the height of blade can be varied to give additional power without affecting the other proportions; but in small machines, on account of the big angularity between adjacent blades, this must be kept down to a minimum. The general practice seems to be to make this height not more than one-eighth of the diameter of the wheel.

18 The pitch of the jets is limited in this machine in the same manner as it is in the Terry, and reference to Fig. 2 will show that the following approximate proportions must be kept:

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19 Let θ and θ_1 represent the first and second inlet angles respectively, and ϕ the angle of discharge after the first action on the wheel; then,

$$E = \left\{2\left(\frac{A}{\sin\theta} + K\right)\left(\sin\alpha + K\right)\cos\alpha\cot\phi\right\} + \left\{(2R + K)\sin\alpha\right\} \ldots\ldots [4]$$

Assuming the angles θ and θ_1 to be 20 and 15 deg. respectively, the discharge angle to be 35 deg., and the dimension K to be 0.75 in., we get:

$$E = 18A \ldots\ldots [5]$$

where A is the width of the jet at outlet and E is the pitch of jets.

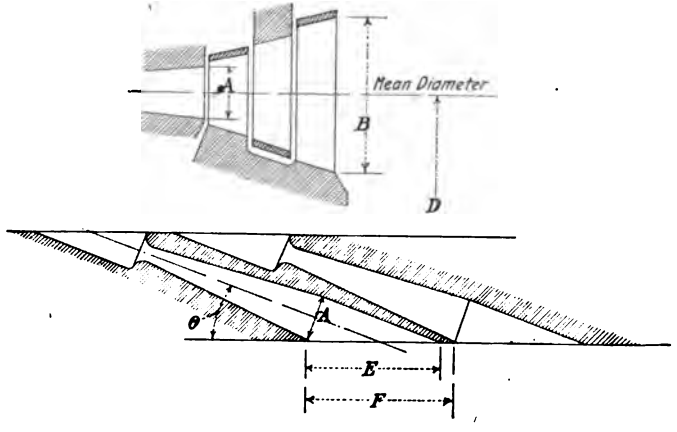

FIG. 3 CURTIS-TYPE TURBINE

20 Taking the maximum height of blade, H, as $D/8$, and the radial height of the jet as $0.9\,H$, then we get the area of one jet

$$A_1 = \frac{D}{8} \times 0.9 = 0.1125\,AD$$

21 The pitch of jets has been found to be $18\,A$, therefore the maximum number of jets around the circumference is $D \times \pi/18\,A$, making the maximum outlet area

$$0.1125\,AD \times \frac{\pi D}{18\,A}$$

or C, the capacity of the machine as before, is $0.0196\,D^2$. Or, in terms of total steam as above,

$$C = 0.0196\,D^2\,(4.6\,P_s + 2160) \ldots\ldots [6]$$

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22 *The Curtis Type* (Fig. 3). In the Curtis machine with a given diameter the limiting dimensions are the height of blade and the percentage of circumference that it is commercially possible to fill with jets, it being understood that it is theoretically possible to have the jets extend over the complete circumference.

23 Referring to the limiting blade height, this has been found to be about $D/8$ in small machines; this is by no means the limit as far as permissible blade height is concerned, a ratio of 5 to 1 being quite common in larger machines, but the ratio of 8 to 1 is all that is necessary to bring the capacity up to the general commercial limits of the frame.

24 Regarding the ratio E/F, the relation between the theoretical and the commercial is approximately 75 to 92, depending on the form of jets and the material used.

25 A fair value to take for the ratio of the height of the last row of blades to the nozzle height, B/A, is 2.5. Taking $B = D/8$,

$$A = \frac{D}{8 \times 2.5} = \frac{D}{20}$$

therefore

$$\text{Area of outlet of jet} = \left(\frac{D}{20}\right)^2 \times \frac{\pi}{4} = 0.00196\, D^2 \quad \ldots\ldots [7]$$

$$\text{Pitch of jets} = A \times \operatorname{cosec}\theta \times \frac{F}{E} \quad \ldots\ldots [8]$$

Taking the ratio $\frac{F}{E} = \frac{1.0}{0.9}$,

$$\text{Number of jets} = \frac{D \times \pi}{D/20 \times \operatorname{cosec}\theta \times 1/0.9} \quad \ldots\ldots [9]$$

$$\text{Total area available at mouth of jets } (C) = 0.111\, D^2 \sin\theta \quad \ldots\ldots [10]$$

Assuming a jet angle of 20 deg., we get

$$C = 0.038\, D^2 \text{ with round jets} \quad \ldots\ldots [11]$$

or

$$C = 0.0485\, D^2 \text{ with square jets} \quad \ldots\ldots [12]$$

or, in terms of total steam as above,

$$Q = 0.038\, D^2 \times (4.6\, P + 2160) \text{ with round jets} \quad \ldots\ldots [13]$$

and

$$Q = 0.0485\, D^2 \times (4.6\, P + 2160) \text{ with square jets} \quad \ldots\ldots [14]$$

26 *The Kerr Type.* The principle on which this machine is designed calls theoretically for a number of stages equal to the

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square of the number of rows of blades or actions in the multi-velocity type with the same diameter of wheel.[1]

27 If we increase the diameter of the wheel to reduce the number of stages, for example, if we design a 2-wheel Kerr to be theoretically equivalent to a 2-row Curtis as far as purely theoretical turbine efficiency is concerned, and if we keep the stresses in the wheels the same in both instances, the diameters and weights of the wheels will be very materially increased. In addition the skin friction will be also increased. As this is a serious factor in small machines it is better to keep down the diameter and increase the number of stages. Within the limits controlled by the ratio of blade height to mean wheel diameter it will be found that from a shop-cost standpoint also it is more economical to increase the number of stages rather than increase the diameter to get the equivalent effect.

28 The cost of wheels of even section varies as the square of the diameter. If the same section of wheel was permissible with either large or small wheels it will be seen from Fig. 4 that the cost of wheels in both instances would be the same. But we have seen that if we are to keep our stresses down to the same factor in each case, then the cost of the wheel element is greater with the fewer stages.

29 Of course, we have to take into consideration the additional number of diaphragms and stuffing boxes, but as the pressure difference decreases with an increase in number of stages the thickness and the weight are in turn affected. So much depends on the general design of the machine that it is difficult to formulate any rule for the relation of weight of the casing to the number of stages, but calculations based on a purely theoretical basis would indicate an advantage in favor of more stages. From a study of the Kerr designs it would appear that this contention is correct.

[1] Let V_w = wheel velocity in both cases
K = constant representing velocity ratios and other factors common to both
H = B.t.u. available in total range of expansion
N = number of rows of blades in a pressure or Kerr type
N_1 = number of rows of blades in a velocity or Curtis type
h = B.t.u. per stage
R = number of rows of blades in Curtis type per stage.

The steam velocity per stage = $8\sqrt{h \times 778}$
$h = KV_w^2$ for Kerr type
$= (KV_wR)^2$ for Curtis type
$H = h \times N$ and $h \times N_1$, respectively
$N = N_1R^2$

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30 Regarding the limitations of a given frame of this design in order to bring it to a basis comparable with the other designs we have been considering, we must first of all neglect the number of stages. The last stage is now equivalent to the last row of a Curtis machine. Therefore with a given diameter the maximum capacity is the same (the leaving losses of course being the same in both instances).

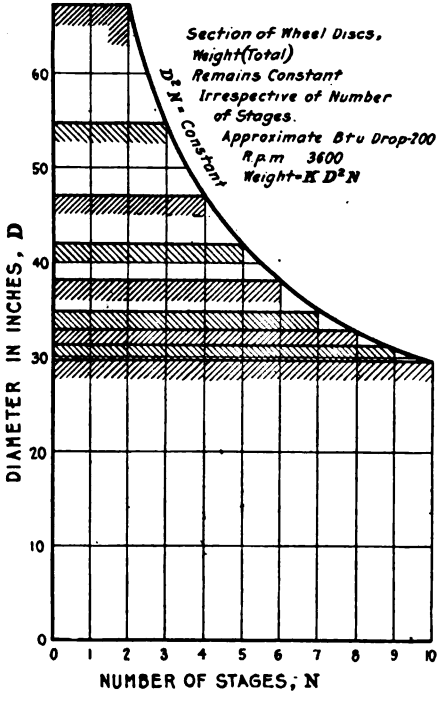

FIG. 4 WHEEL WEIGHT OF KERR-TYPE WHEELS

31 As mentioned above, for a given theoretical efficiency the number of stages in a machine of this design varies as the square of the number of the rows of blades in the Curtis design, so that it is hard to tell at first sight how this machine can be competitive if an efficiency even approximating that obtainable with the Curtis design is to be obtained. The fact nevertheless remains that this machine is competitive, and very much so at that, and has a market. There can be only one solution to the problem, namely, cheaper manufacturing costs; and a study of the designs, with the standard-

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ization they have adopted of all parts, leaves little doubt that this is the answer.[1]

32 Summarizing the above, therefore, we get the frame capacity of the respective designs in terms of jet-outlet area as follows:

Terry	$0.00395\,D^2$
Westinghouse	$0.0196\,D^2$
Curtis	$0.0485\,D^2$
Kerr	$0.0485\,D^2$

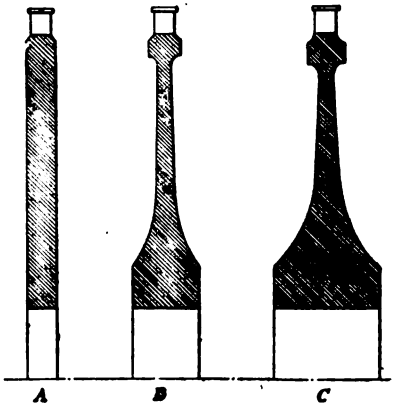

FIG. 5 FORMS OF WHEEL DISKS REFERRED TO IN TABLE 1

33 To compensate for the shortcomings of the Westinghouse and Terry designs as regards capacity, the makers claim distinct

TABLE 1 EFFECT OF SPEED ON DESIGN AND COST OF WHEELS

Form of disk (see Fig. 5)	A	B	C
Outside diameter of disk, ft.	2	2	2
Max. stress, lb. per sq. in.	17,000	17,000	17,000
R.p.m.	4000	5000	6000
Weight, lb.	120	105	145
Cost of material at 8 cents per lb.	$ 9.60	$ 8.40	$11.60
Estimated labor cost (not including blading)	2.60	3.90	4.55
Overhead, 200 per cent labor	5.20	7.80	9.10
Total shop cost	$17.40	$20.10	$25.25
Ratio of cost	1.0	1.16	1.46

advantages for their designs over the Curtis on account of the single-wheel construction as compared with two or more wheels or two or more rows of blades.

[1] An interesting comparison showing the effect of speed on the design and cost of wheels is given in Table 1.

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34 The strongest argument in favor of the Terry design is the elimination of all fine longitudinal clearances, and this is unquestionably a very important one, especially when the machine is sometimes called upon to take care of external-thrust loads from unbalanced pumps, etc. But with modern designs where only two actions or two rows of blades are necessary, it is impossible to obtain the same efficiency as with a Curtis type, as will be explained later, and it is questionable whether the advantages are sufficient to compensate for the decrease in efficiency provided an adequate thrust bearing is employed.

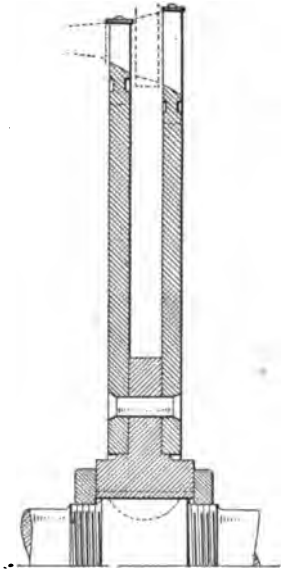

FIG. 6 BUILT-UP TERRY CURTIS WHEEL

35 Regarding the first cost, with two wheels built up of saw-steel disks as shown in Fig. 6 and bladed with extruded metal, the finished cost is about the same as for the standard Terry design. This is in a great measure accounted for by fact that the Terry design calls for a great amount of hand finishing in the wheel and reversing chambers that is not called for in the other design.

36 With the Westinghouse design we have the same necessity for retaining the small axial clearances as in the Curtis, so the single-wheel element is the only advantage, but it is much lighter than the Terry and therefore lends itself much more readily to overhung

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design than either the Terry or the Curtis. With regard to first cost, it would appear that the first cost of the reversing chambers in this design would be as high as that of another row of blades with simple nozzles and cheap construction of extruded guide blades.

37 One factor that has had a great deal to do with the necessary modifications to the designs that were practicable seven or eight years ago is the great increase in the operating speed now called for in the average small-turbine unit.

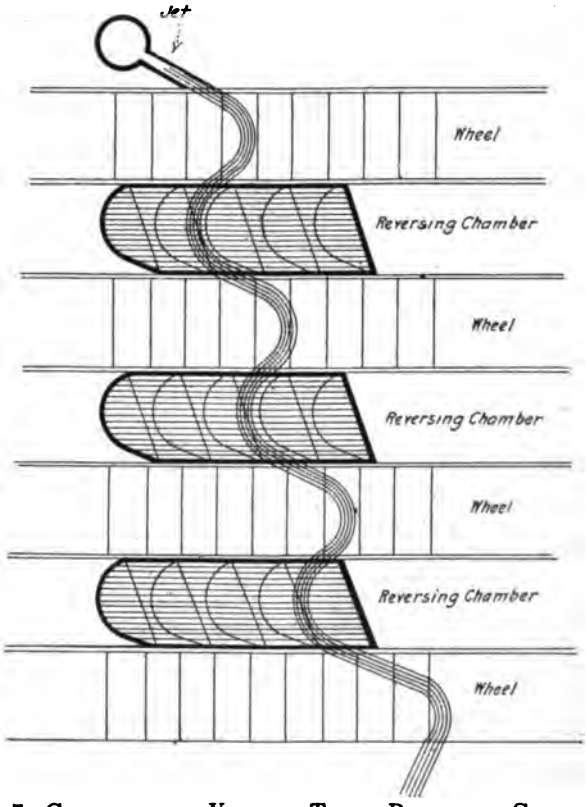

FIG. 7 CONVENTIONAL VIEW OF TERRY REVERSING CHAMBERS

38 It is only recently that gears have been reduced to a commercial basis, with the exception of the De Laval Co., who confined their output of gears exclusively to their own apparatus, so that in the earlier days the other manufacturers had the speed of their turbines entirely controlled by the connected apparatus. Furthermore, the speeds of that apparatus at the time of which we are speaking was

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very much lower than it is now, so that a velocity ratio of 8 to 1 was common practice in those days.[1]

39 The Terry machine was at its best when subjected to these conditions. The reversing chambers[2] were arranged as shown in Fig. 7, and the path of steam was approximately as shown, extracting right up to the limit of the available energy in the steam. Owing to the necessary mixing of primary and secondary steam in the reversing chambers, it is impossible to judge how many true actions are actually obtained, — hardly more than three. Inasmuch as in the Curtis machine three rows of blades for the same velocity ratio give better results than four, it must be assumed that the fourth chamber in the Terry probably takes care of the spilling that occurs throughout the cycle.

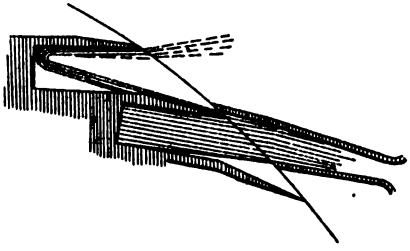

FIG. 8 ILLUSTRATING "SPILL" IN TERRY REVERSING CHAMBER

40 The action of the steam in the Curtis machine is a straightforward proposition and easy to follow, but in the Terry it is the most complex problem in all turbine work, so much so that authorities in writing about it barely touch on the theoretical considerations.

41 In spite of this uncertainty, very excellent results are obtained at these low speeds and the efficiencies are competitive with any

[1] By velocity ratio is meant the ratio of the steam speed issuing from the nozzle to the peripheral speed of the wheel. For instance, expanding from 150 to 0 lb., velocity at outlet of jet referred to the plane of rotation of the jet is approximately 2000 ft. per sec. A 2-ft. wheel running at 2500 r.p.m. has a peripheral velocity of approximately 250 ft. per sec., therefore the velocity ratio is

$$\frac{V_s}{V_w} = \frac{2000}{250} = 8$$

[2] Explanation of Figs. 7 and 10. While there is of course only one wheel and one set of reversing chambers in a Terry machine, it is difficult to make an intelligent diagram when showing only the one wheel and reversing chamber. The conventional view is supposed to represent the same wheel and reversing chamber at different stages of a revolution.

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type; but at higher speeds its efficiency as compared with other types falls rapidly away.

42 To refer briefly to a few experiments that were carried out to determine the possibilities of this machine at higher speeds, we must first of all bear in mind that there is a necessary "spill" and mixing of steam at different velocities throughout all reversing chambers (Fig. 8), and therefore the steam must in a great measure find its own path; so experiments were tried with a chamber free of all division plates, giving the steam entirely its own way. This gave very inferior results to the standard chamber, however, showing the necessity of a certain amount of guidance to the steam. A compromise was suggested by Lee (Fig. 9), giving a partial guidance to the

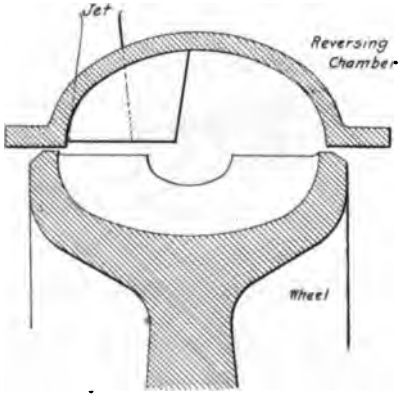

FIG. 9. LEE'S METHOD OF PARTIALLY GUIDING STEAM IN TERRY CHAMBER

steam, but this does not yield on test the efficiency of the original design.

43 Now, to come to the effect of increased speed, it would naturally be assumed that with a velocity ratio of 4 to 1 the same improvement would be obtained by leaving off two reversing chambers as we get by leaving off rows in the bladed type of machine, but this is not so; the speed of the wheel having been increased, the point of discharge from the first bucket has advanced to such an extent that some of the discharge actually enters the *last* reversing chamber (Fig. 10), so that to make an efficient 2-action wheel the reversing chamber should cover the same arc of the circumference as a 4-action machine. A large reversing chamber specially designed for one reversal was extensively tested out, the most careful

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attention being paid to the inlet and outlet angles, but the result was substantially the same as with the standard chambers. A divided chamber was next tried, similar to the Riedler-Stumpf, but if there was any advantage gained by the additional guidance it was lost in increased skin friction, as the results were still about the same.

44 The minimum length of the path of steam in a 2-action Terry machine is at least five times that in a properly designed Curtis machine, and this, together with the difficulties already mentioned in properly guiding the steam without mixing from one velocity

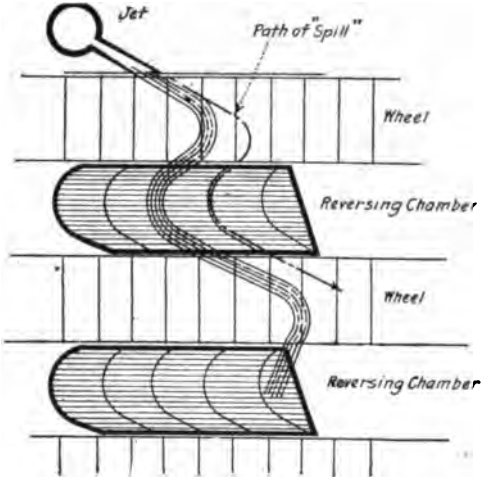

FIG. 10 PATH OF SPILL IN TERRY REVERSING CHAMBER

stage to the next, practically eliminates the commercial possibilities of this type for the higher speeds now demanded.

45 It is now generally acknowledged that from a design standpoint the small machine must be laid down on a totally different basis to the larger machines. The principal reasons for this are:

a High thermal efficiency is in a great many cases unnecessary on account of the economical utilization of exhaust steam; and as economy bears a definite relation to first cost, a highly efficient machine is often a mistaken investment

b The class of labor employed in the average station to look after auxiliaries is very inferior to that employed on the main engine-room floor. These machines which are called upon for continuous operation are often located

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in places where no other well-finished piece of machinery would be expected to run.[1] The designer must therefore consider simplicity and durability first, with as high an efficiency as possible; but he must sacrifice efficiency if in any measure it will interfere with the first essentials mentioned.

46 While the small-turbine auxiliary has all the appearance of a very elementary and simple engineering proposition, this is by no means the case, as any manufacturer knows; and problems equally complex with those confronting the designer of large machines have had to be solved, and a great many are by no means yet solved. We have only to consider the comparatively few firms that are competing in this line today with the number that have entered it, evidently tempted by the apparent simplicity and big profits, and finding out too late that it is a more difficult proposition than appears on the surface. The theoretical design, that is, the proportions of nozzles, blades, wheels, etc., presents no difficulties, but the *mechanical design* of such parts as the bearings, glands, governor, etc., is what determines success or absolute failure.

47 It is not within the province of this paper to go into these details any further than to point out in a general way some of the problems that have had to be solved. Among the more important of these are lubrication, packing and regulation.

48 Forced lubrication being impracticable in small machines for general-auxiliary purposes, the ring-oiled type has been called upon to operate with duties previously considered impossible, and to operate continuously with a bearing-box temperature in the neighborhood of 250 deg. fahr.

49 Glands or stuffing boxes are sometimes called upon to pack against a back pressure of 120 lb., while 20 and 30 lb. are common. It must be borne in mind that the soft-packing stuffing box as used in reciprocating machines is impracticable in turbine work on account of the high rubbing speeds.

50 The design of a satisfactory governor, the essential feature of which is simplicity, but having a characteristic approaching the more elaborate types, has presented many difficulties; so has the governor valve, which must be as small as possible to minimize cutting at light loads, but must not crowd or stick when passing the maximum amount of steam required.

[1] Several cases are on record where machines have actually run for considerable periods under water without damage.

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51 The above constitute the essential components governing details of the performance of the turbine itself, but there is one other and a vital factor to be considered, and one that comes directly within the present subject-matter — the satisfactory performance of the whole unit. As in all other classes of machinery, certain mechanical troubles will always arise from time to time, but it is safe to say that today the general behavior of a turbine unit will compare very favorably with any other piece of apparatus in a power house. But to return to the more general considerations of the unit as a whole, there are some very important factors to be taken into account that are peculiar to this class of apparatus, and which have a direct bearing on the general design.

52 The most important of these is of course the necessity for true alignment. Where the unit is built in one shop the designer

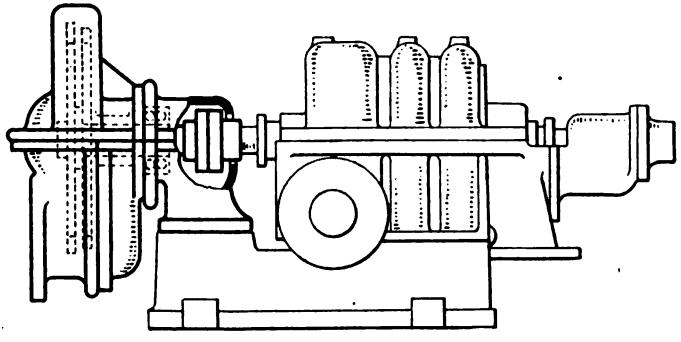

FIG. 11 PUMP AND OVERHUNG TURBINE

has a distinct advantage, inasmuch as he can so design both ends of the apparatus as to make one rigid unit; but where the two ends of the unit are built by different parties, it is a different proposition.

53 The average so-called flexible coupling will not satisfactorily take care of misalignment, the bedplate cannot be commercially designed that will stay true from test floor to foundations; so that no matter what care has been taken in the shops, a realignment after erection becomes an unfortunate necessity in even the smallest units. There is an extensive field for improvement in general design to eliminate this. Various schemes have been advanced recently resulting in a marked improvement in this direction, such as the 3-point support, and the 3-bearing unit with the elimination of the flexible coupling. The latter is practicable where one firm builds the whole unit, but otherwise up to the present it has

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not worked out very satisfactorily. The main reason for this is best explained in the case of electric-generator units. If the turbine maker takes away one of the generator bearings, in other words, disturbs the assembly of the complete generator as shipped from the manufacturer, he disclaims responsibility for anything that may happen to that part of the apparatus on the road.

54 In blower work the proposition is more practicable, but only when the unit is lined up by the turbine maker or one equally appreciative of the necessity of accurate workmanship.

55 To overcome this trouble the Steam Motors Co. have recently placed on the market the design of machine shown in Fig. 11. This machine is supplied with only one bearing and solid coupling for connecting to the driven apparatus. By taking a standard pump or blower and removing one bearing and fitting a solid coup-

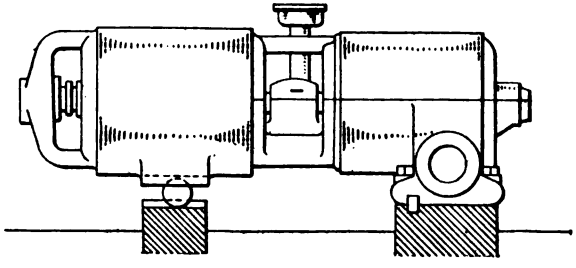

FIG. 12 RIGID-FRAME DESIGN OF TURBINE AND PUMP

ling to the shaft, the combination of steam motor and pump becomes a 2-bearing unit, with a very much shorter bedplate and the elimination of any misalignment troubles.

56 In larger machines, one of the most pleasing in effect and at the same time most radical departures made in recent years to overcome the difficulties of misalignment was the introduction by Mr. R. H. Rice, Mem.Am.Soc.M.E., of the General Electric Co., of the so-called rigid-frame design. From Fig. 12 it will be seen that the bedplate has been entirely eliminated and the whole structure so designed that both ends are bound to stay in line irrespective of foundation conditions, so reducing the personal equation in erection to a minimum. In erecting this machine only one end is anchored, as shown in Fig. 12. The generator end is mounted on a sliding key, allowing free movement endwise, and on a narrow transverse foundation plate on which the generator can rock to

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compensate for any vertical movement of the turbine due to varying temperature. In effect the machine rests on its foundations, as shown diagrammatically in the figure.

THE SALESMAN'S AND CUSTOMER'S ASPECT

57 What might be called the truly commercial aspect of this situation, i.e., those phases of vital interest to the salesman and customer, presents many interesting problems. To begin with, we must forget that we are dealing with steam turbines in the sense that we have been accustomed to, when we have only been considering prime movers. For auxiliary purposes the small turbine is becoming the standard method of drive. That means that it is getting into the class of the electric motor. It has already passed the stage of "being built" and is now being successfully manufactured in quantity.

58 There is, however, still a great deal to be accomplished before the machine can be satisfactorily manufactured to be sold from stock. At first sight it might appear that this is almost out of the question, especially when we see such a diversity of specifications as accompany the average contracts for small turbines today, but when the number of these machines that are now being turned out at the present time and the fact that the market is increasing rapidly are considered, it is surely only a matter of time when some form of standardization will be absolutely necessary. In the electrical industry we have seen the wonderful advantages, both to the manufacturer and customer, of the rules laid down by standardization committees, and we wondered why we had not adopted them sooner. Perhaps not to the same degree of perfection, but certainly to some extent a standardization of small-turbine specifications is not only possible but quite practicable. As long as the customer calls for something special, and everybody is willing to build it, not only does this customer have to pay for it, but the standard machine will cost more, on account of the interruption to the manufacturer in putting through lots.

59 Let us then consider where the possibilities lie in this direction, analyzing the various requirements of the average specification which call for rigid guarantees under the headings: (*a*) steam-consumption guarantees at certain loads with fixed or various steam conditions; (*b*) speed-regulation guarantees, and when connected to electric generators voltage-regulation guarantees *in addition;* and (*c*) various load requirements with varying steam- and

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back-pressure conditions. In addition there is a diversity of requirements as to fittings, such as water-pressure regulator, emergency governor, strainer, gages, etc.

60 Regarding (*a*), this is a much-debated point when discussing small turbines. Granted there was a time when the small turbine was very wasteful of steam, that time has now passed and the builder of small turbines today meets any guarantee he makes; and at the very worst it is questionable whether a small turbine was ever built that consumed steam at a rate comparable with some direct-acting pumps. But there was never any serious criticism raised with such pumps on that score nor was the manufacturer even asked for a guarantee. The consulting engineer or purchaser feels that he cannot possibly buy a steam turbine, no matter how small, unless he imposes numerous stringent guarantees as regards steam consumption. The fact that an auxiliary rarely operates under the steam conditions as specified, and therefore the guarantees as made bear but little relation to the actual performance, does not enter into his consideration at all.

61 When a manufacturer advances any argument relative to the unimportance of steam consumption, he is generally misunderstood. The customer feels he is trying to evade any responsibility along these lines and sell an inferior piece of machinery. Let us look at that from another standpoint. The manufacturer today builds one line of machines. There are so many cases where efficiency is of prime importance that the machine as built must be capable of meeting the guarantees as demanded by the market. Furthermore, any machine with a witness-test clause added on cannot be put through the shops independently but must necessarily be one of a lot of identical machines. If this machine meets its guarantee on test it is only fair to assume that the others cannot be far off the mark. In this connection a concern regularly manufactures machines for the U. S. Government under specifications that are most rigid as regards performances on test, yet with the possible exception of material inspection in some cases, these machines are standard in all respects.

62 Witness tests are costly. The manufacturer naturally cannot notify the customer exactly when a machine will be ready for the shop tests, and would not want him present then if he did, so that any delay in a busy shop, waiting on the customer's convenience and a duplication of the tests, must eventually be paid for directly or indirectly by the purchaser.

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63 One more word on the absurd multiplicity of guarantees sometimes called for. It is no exception to find in some propositions, particularly from pump companies, a request for 15 or 20 guarantees under different conditions for a non-condensing machine where the exhaust is to be used in the feedwater heater.

64 Clause (*b*), speed-regulation guarantee, is necessarily of vital importance in such work as generator drive, but it surely is of no importance whatever when the speed of the turbine is primarily governed by a pressure regulator as in the case of a boiler-feed pump or forced-draft set controlled in a similar manner, yet the manufacturer has to religiously put in his 2 per cent clause.

65 Even with generator drive the average clauses are too exacting for the good of the customer. Why need we specify a close speed variation when we already specify a certain variation in voltage? The compensated-wound generator can give flat compounding with a big speed variation, and a reasonably large speed variation means stable governing, whereas a sensitive governor means instability and a tendency to hunt. We have only to look at the average a. c. machine to realize how essential a reasonably wide speed variation is for satisfactory parallel operation.

66 Again, to obtain close speed variation on test means very delicate fitting and adjustment of the governor valve. The valve must shut absolutely tight, and any valve built this way is subject to cutting in service; whereas, if a wider speed variation had been permissible in the first instance, a more durable valve could have been installed.

67 Regarding (*c*), load requirements, there is a strong tendency to introduce the *maximum rated* standard into the small-turbine field, and common sense tells us that it is the only proper competitive basis; but is the adoption of this standard commercially practicable under existing conditions? As far as the turbine itself is concerned there is no argument, the output can be accurately estimated; but does the same degree of certainty exist among the pump and blower makers?

68 With the repeated changes in design, the limited testing facilities in the average pump-maker's plant and the almost impossible proposition of making accurate blower tests on a commercial basis, is it feasible at the present time to order a turbine without an overload margin to take care of errors that are not only excusable but are to be reasonably expected? Experience tells us that a certain leeway *is* necessary, — the turbine maker knows this, and often

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finds that the addition of another jet, over and above that necessary to meet the contract, is a good investment. This principle is not right if we are to have fair competition among turbine makers; it is only natural that the pump maker will favor the type of machine that *he knows* will give him a good big overload. The worst feature of this situation is the fact that in some cases in a cut-price job the pump maker has *relied* on the overload capacity of the turbine to give full load at the pump.[1]

69 The adoption of the maximum-rating standard by *all* turbine makers and their rigid adherence to it would in a great measure solve this whole problem. Granted that allowances are necessary, they should all be made by the pump or blower maker, who should be the best judge as to the leeway advisable, and he should order his turbine accordingly.

70 The question as to whether the maximum rating will be satisfactory to the customer is another matter to be considered. With the customer educated to the limitations of the turbine there should be no difficulty; but as long as he thinks it can be loaded up to breaking-down point like a motor, there will be dissatisfaction if the machine fails to carry full load when the steam pressure drops. All that is necessary in this case is a clear understanding between the contractor and purchaser as to the conditions *necessary* to obtain full load.

	Steam press., lb.	Quality, per cent	Back press., lb.	Hp.
Specified conditions	150	100	0	100
Operating conditions	140	98	2	83

71 It might be well to bring out here an important point in connection with non-condensing auxiliaries that run at full load continuously. With a condensing machine, considerable variations in initial steam pressure can take place without materially affecting the output, but in a non-condensing machine a multiplicity of small deviations from the contract conditions, each insignificant in itself, can have a very marked effect on the output, as will be seen from the preceding table, which compares the conditions as they would

[1] A representative of a pump manufacturer was once frank enough to admit that a certain turbine firm always got the preference because it was more liberal with its overload capacities.

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be specified in an average contract with conditions that could reasonably be expected in service.[1]

72 With a view to setting forth how the theories mentioned above can be worked out in practice, a suggested Code of Practice is given in the Appendix.

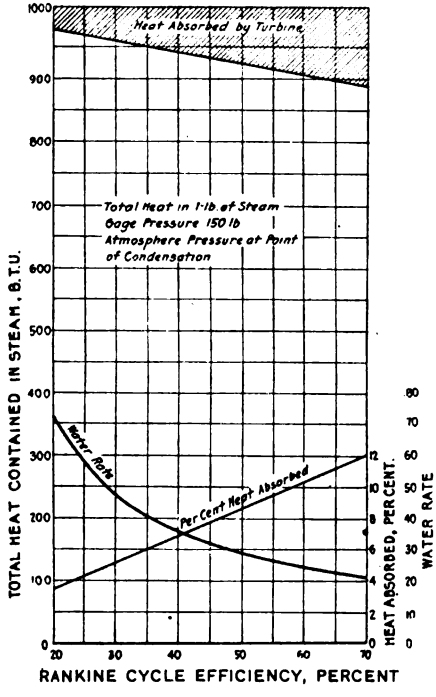

FIG. 13 EFFECT OF WATER RATE ON HEATING VALUE OF EXHAUST STEAM

73 The question of steam consumption, with its true relation to the overall efficiency of the plant, has lately been receiving much more attention than formerly. In stations and industrial plants where all the exhaust can be utilized, the thermal efficiency

[1] In this connection it might be well to enlarge on one point often overlooked by the manufacturer and customer alike — the necessity for very liberal allowances in machines operating at very low pressures.

Operating with atmospheric exhaust an initial drop in steam pressure of 10 lb. from 150 lb. means a reduction of available B.t.u. at the turbine of 3 per cent, whereas the same drop at 60 lb. (common in sugar-refinery work) means over 10 per cent. Therefore velocities permissible under the higher pressures must be considerably cut down when it is desired to maintain full load at around 60 or 70 lb.

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of the auxiliaries can vary very considerably without an appreciable effect on the coal pile. Fig. 13 shows what a relatively small effect a very large range in water rate has on the heating value of the exhaust steam.

74 However, in stations where there are times when all the exhaust cannot be economically utilized, the question of the auxiliary efficiencies becomes of serious importance. To meet this condition a great many radical changes have been made in the general layout of this part of the apparatus, particularly in the introduction of geared driven pumps, etc., in place of the low-speed direct-connected type. Any innovation of value here naturally means complications, in the same manner that any marked improvement in the steam consumption of the turbine itself must necessarily be made at a sacrifice of simplicity. Can we afford to do this? Will the little saving that at best can be made commercially in any design of small turbine give the net result required? Is it not better to accept the best efficiency conducive to maximum simplicity and reliability, and be content with that; then, when the point is reached where more exhaust than that supplied by a certain number of auxiliaries is required, to switch over to electrically driven apparatus? The combination steam- and electrically driven unit meets this situation admirably.

75 The ideal way to distribute the units would be to begin with the turbine units in all places that receive the least attention and such places as boiler-feed pumps that must not be shut down in case of any electrical disturbance, and keep the electrically driven units on the main engine-room floor as far as possible.

THE MANUFACTURER'S POLICY

76 Regarding the question of policy between the manufacturers of the respective parts of a complete piece of apparatus, and the combined policy of manufacturers towards the customer, the first question that arises is, Why should there be any difference here from the policy adopted in other branches of the trade? Theoretically, of course, there should be no difference, but many conditions unfortunately exist, peculiar to this business, that make this question of policy a very vital one and worthy of serious consideration in any attempt to solve the commercial problem under consideration. When an engine-driven or motor-driven set is sold, the correspondence between the respective manufacturers consists of an interchange of formal orders; but we have a long way to go before we

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arrive at the same businesslike procedure in connection with turbine units.

77 These arguments, of course, do not concern the builder of the combined unit, who in this respect will always have a distinct advantage over the other manufacturers.

78 Any standardization along the lines suggested above will do more than anything else toward clearing the atmosphere of such questions as the limitations of apparatus furnished, the long interchange of correspondence relative to unimportant partial-load performances, and the responsibility for imperfect erection at the customer's plant.

79 Our one idea in all these considerations is the ultimate reduction of factory costs. Selling costs do not enter into this argument. Factory costs consist of two essential items — manufacturing expenses and overhead. Standardization and the elimination of special machines will help our shop costs or manufacturing expenses. The next question is, what can be done to reduce overhead expenses? To the layman it would appear that the latter should consist of the merest clerical work in such a simple apparatus as a small turbine, but there is today in addition a very heavy expenditure that must be borne by all manufacturers alike, and that is for the maintenance of a trouble force in the engineering department at the works as well as outside, an expense out of all proportion to the legitimate requirements of the situation. It is here where the question of policy comes in, and it is here where we can look for one of the biggest economies.

80 There is a deplorable lack of coöperation existing at the present time between the average turbine builder and many of the pump and blower builders. If a unit is reported unsatisfactory for any reason after erection and the report goes to the pump builder, he will almost invariably assume the said trouble is entirely the fault of the turbine and call upon the turbine maker to send a man to remedy it before he makes any investigation as to the performance of his own apparatus, and vice versa if the original report goes to the other party. Even at the station it is common practice for the representative of one end of the apparatus to go out of his way to explain to the customer in detail how the trouble is entirely up to the other end, and this state of affairs is by no means confined to the erecting staff, who cannot always be blamed for taking this attitude, but extends to the higher officials of the company who ought to know better. This state of affairs does not help the customer, but

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it goes a long way toward making him buy his next machine from a firm manufacturing the whole unit. This condition may to a certain degree be expected, but surely it is possible to formulate some definite line of procedure that will in a great measure relieve this present unhealthy situation.

81 One of the prominent obstacles to the application of any hard-and-fast rule is the fact that firms cater to the larger corporations and feel that it behooves them to go to unjustifiable expense in case of trouble to keep in their good graces for future business. A sound and uniform policy on the part of all manufacturers would put each one in a much stronger position.

82 A few suggestions as given below present themselves at this time, each one of which, if adopted by one or two individual firms, would probably result in serious disaster, but if conscientiously adopted by all firms would undoubtedly have a mutually beneficial result.

83 If a turbine is bought by a pump or blower maker, said purchaser must accept the machine on leaving the maker's works as having met all its guarantees (as in the case of reciprocating engines and motors). If, however, subsequent performance warrants a test to determine the performance of the turbine, said test must be arranged for and carried out at the expense of the purchaser. The expenses of a representative of the turbine maker who must be present to be included. If the tests show conclusively that the turbine has failed, then all the expenses are automatically transferred to the turbine maker and he is to be allowed, say, two months to make good with his apparatus before rejection.

84 If a test on sight is impossible, the maker can demand that the machine be returned to the works, where a witness test can be made in the presence of the purchaser's representative, the purchaser paying all expenses, including freight, if the machine on test is not at fault, and vice versa as above.

85 Neglecting the few instances where both ends of the machine fail, there should be no such thing as dividing the expenses. The machine is right or wrong, and the responsible party should pay all. Cases are on record where a hard-and-fast rule of this kind would have eliminated years (not months) of controversy over the equitable division of expenses. If the respective parties cannot come to terms, then they should agree to take the decision of an arbitrator mutually agreed upon. As soon as any controversy arises his services should be sought immediately, and not as at present (when this

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course has been adopted) after months of expensive haggling, with the resulting hard feeling that this invariably creates.

86 If the customer disputes the performance of the whole installation, it rests with him to conduct the necessary tests at his own expense with the same adjustment of costs as above, the maker's engineers to be invited to all such tests.

87 In all cases of trouble, the customer must first of all see to it that he notifies the right party, i.e., the master contractor. If the turbine breaks down, and the unit is bought from a pump maker, it is primarily the duty of the pump maker to apply the remedy. All dealings with the customer must be through him. Again, if a machine is bought F.O.B. factory from a reputable concern, and trouble is experienced after erection and the services of an expert are requested, the request should be sent by a responsible member of the purchaser's firm and be considered in the light of a formal order covering said expert's expenses. If the trouble is due to defects in the apparatus, the manufacturer cannot send in a bill and expect any repeat orders.

88 One of the hardest propositions the manufacturer is confronted with today is to collect for expenses when the trouble has been entirely due to the engineer's absolute neglect of the instruction book furnished with the machine, or to other causes for which the manufacturer should in no way be held responsible. If all makers could see their way to adopt a policy of this kind, requests for men by irresponsible under engineers would rapidly decrease. The fact is, that if the engineer knows at the outset that if the trouble is caused by his own negligence and the expense is going to be charged against him, he is naturally going to make sure of his ground before he risks the displeasure of his superiors by showing his incompetence to adjust the machine or by running up unnecessary bills in his department.

89 In like manner the sub-contractor must expect a formal order from the master contractor for any expert services.

90 In conclusion, this is not a matter that concerns only the manufacturer from a financial standpoint. It concerns the purchaser, inasmuch as the selling price of the apparatus will be reduced. It also concerns the manufacturer from the standpoint that any advance along the lines suggested cannot have any other effect than to eliminate unpleasant experiences with the customer and thereby increase the popularity of the turbine-driven unit.

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APPENDIX

SUGGESTED CODE OF PRACTICE

[1] All steam and exhaust flanges will be in accordance with the A.S.M.E. Standard.

[2] The direction of rotation will be clockwise when viewed from the coupling end.

[3] Quotations are F.O.B. point of manufacture.

[4] For operating temperatures up to and including 550 deg. fahr., cast iron will be satisfactory in all steam passages. For temperatures above this steel walls will be used in all places subjected to this temperature. Internal parts such as valves, valve seats, etc., may be of monel metal or other composition at the discretion of the manufacturer.[1]

[5] Blading material will be left entirely to the discretion of the manufacturer.[1]

[6] All machines for mechanical drive, i.e., machines not connected to electric generators, will be tested before shipment to 20 per cent above normal speed. Generator sets will be tested to 10 per cent above normal speed.

[7] The machine will carry rated full load with 90 per cent specified steam pressure at the turbine, 1 lb. higher back pressure or 2 in. lower vacuum, the steam at the turbine having a dryness factor of not less than 97 per cent. The above allowances are not to be considered as accumulative. For instance, if the steam pressure is down to 90 per cent, other conditions must be normal.

[8] Steam-consumption guarantees in all machines below and including 300 hp. will be confined to full load under specified operating conditions.[2]

[9] The machine will be considered as having met its guarantee if the steam consumption on test is within 5 per cent of the guarantee figures. No penalties or bonuses will be enforced until this limit is exceeded. If it is exceeded the full penalty or bonus will be enforced. For example, 5 per cent excess, no penalty; 5½ per cent excess, full 5½-per cent penalty or bonus to be enforced.

[10] When contract conditions are not available on test, correction factors given in the U. S. Navy Dept.'s Specifications for Turbo Generators, Form 17 G. 5, will be acceptable in interpolating results.

[11] Prices quoted do not include witness tests.

[1] As the material used here does not affect the safety of the apparatus, and as experts do not yet agree as to the best material to use in any particular case, it would appear that the manufacturer should be allowed to use his discretion here.

[2] The small apparatus that these specifications are intended to embody are rarely called upon to operate at light loads for sufficiently long periods that the difference in water rate between one machine and another can have any perceptible effect on the coal pile. Where jet valves are used for prolonged operation at partial load the water rate automatically becomes substantially the same as full load.

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[12] *Speed regulation.* Generators: The generator will be compounded in accordance with customer's requirements. No speed-variation guarantees will be given. Maximum voltage jump when full load is suddenly thrown off will not exceed 5 per cent.

Turbines for mechanical drive: Where regulating governor is supplied, settled speed variation shall not exceed 3 per cent either way from normal. The maximum jump shall not exceed 6 per cent from normal.

[13] Where overspeed or emergency governor is supplied it will be set for 10 per cent above normal operating speed.

[14] The normal operating speed may vary 7½ per cent either way from that stated in the contract.[1]

[15] Prices quoted do not include the services of an erecting engineer. Customer takes full responsibility for the erection on site, and in case of the necessity arising for the services of an expert, this to be covered by a separate formal order.

[16] Steam and exhaust flanges will be drilled and spot-faced for through bolts where possible. Where studs or tap bolts are necessary, holes will be properly tapped, but no studs or bolts will be supplied with the turbine.

[17] Where abnormal conditions of operation are expected, or the machine is required to operate for prolonged intervals at partial load, hand valves may be fitted as required at extra cost.

[18] The following standard fittings will be included in any steam-turbine contract:

On all sets:

Self-oiling bearings

Gage glasses, or overflow filler cups on machines not furnished with forced lubrication

Oil rings in addition, on all machines designed for forced lubrication

Relief valve fitted to exhaust end of casing. This valve will act as an alarm only, and will not be of sufficient capacity to save casing in case of excess pressure

Stop valve and exhaust valve not included.

In addition to the above,

On generator sets:

Main regulating governor

Emergency governor.

Boiler-feed pumps. When pressure regulator is used, emergency governor only; when no pressure regulator is used, speed regulating governor only.

Circulating and other constant-load pumps, emergency governor only.

Forced-draft blowers. When controlled by pressure regulator, emergency governor only. When not controlled by regulator, speed regulating governor only.

Gas blowers. Speed-regulating governor. Emergency governor.[2]

[1] This clause is perfectly reasonable. The steam consumption is not materially affected within these limits, and such allowances are often necessary to adjust the machine to local conditions.

[2] The addition of an emergency governor is here suggested on account of the lack of attention, intermittent operation and remote control these machines are subjected to.

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[19] Pressure regulators for either pumps or blowers are to be furnished by the customer. Each regulator is to be a complete unit in itself, consisting of regulator mechanism and valve. This to be inserted in the steam line by the customer. There will be no connection between the regulating mechanism and the turbine governor.[1]

DISCUSSION

O. D. H. BENTLEY (written). In defense of the type of turbine the author has chosen to call class "(*b*) Terry, Sturtevant and Bliss"; I would like to call attention to the following facts.

In reference to possible capacity of frame, Mr. London has shown in a very logical way that it is possible to develop a greater maximum capacity per unit diameter with the Curtis than with the Terry, for instance — a feature which is no doubt of vital importance when large outputs are required, but in the class of small commercial turbines under consideration, this factor is not so important as it would first appear. This is due to the fact that turbines of the Terry, Sturtevant and Bliss class develop capacities sufficient to meet the usual commercial requirements. For instance, out of 450 standard commercial turbines manufactured by one concern which are driving forced-draft fans, gas blowers and pumps, the average horsepower was 76, the average speed being 2600 r.p.m. As an example, to commercially meet this average condition with the Terry, Sturtevant and Bliss types, it would be customary to use an 18- or 24-in.-diameter rotor, depending upon the efficiency desired. In order to show an equal efficiency upon a Curtis type, it would also be necessary to use approximately these same diameters; therefore, even admitting that the Curtis type will develop a greater maximum power per inch of diameter, what benefit is this possible excess output if it is not required? In other words, assuming the r.p.m. to be fixed, the water rate establishes the diameter rather than the horsepower.

The diagram given in Fig. 7 does not correctly illustrate the path of the steam through a Terry turbine. The reversals in the rotor and the re-directing chambers are shown in the diagram as making a turn of approximately 90 deg. As a matter of fact, the reversals in the Terry, Sturtevant and Bliss turbines are practically 180 deg. This is true, not only in the rotor but in the stationary re-directing buckets as well. This is an important point for consideration, for

[1] The pressure regulator is a specialty, and any separation of the regulator mechanism from the valve proper means a division of responsibility in case of trouble, resulting in delays and inconvenience to the customer.

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it is the distinguishing feature of the Riedler-Stumpf principle, as utilized in the Terry, Sturtevant and Bliss turbines.

Other things being equal, the amount of energy that a rotor will extract from the steam varies directly as the angular reversal. Inasmuch as the Riedler-Stumpf type reverses the steam practically 180 deg., it is fair to assume that this type of turbine will absorb practically double the amount of energy per reversal compared with the Curtis.

The author states that the action of the steam in a Curtis machine is "a straightforward proposition and easy to follow," but the action of the steam in the Terry (Riedler-Stumpf) type "is the most complex problem in all turbine work;" but he goes on to say, "In spite of this uncertainty, very excellent results are obtained at these low speeds and the efficiencies are competitive with any type." Is it not reasonable to assume that the good results which are obtained can be accounted for by the fact that the Reidler-Stumpf principle permits of a more complete reversal of the steam than is possible with the Curtis?

It is true, as the author states, that what actually takes place in a turbine of this type (Riedler-Stumpf) is "complex." The reason is that the relation between the nozzle, rotor and re-directing buckets is constantly changing and more or less intermittent actions are taking place, for the primary, secondary and tertiary steam are more or less mixed up together. But the fact that the action is not thoroughly understood should not condemn the Riedler-Stumpf principle. On the other hand, does it not indicate that there are even better efficiencies possible when what actually takes place in this turbine is better understood? It must be admitted that the Curtis principle has been highly developed, whereas the Riedler-Stumpf has not, up to date, been given any serious attention.

The author seems to be of the opinion that while it is possible to get high efficiency with this type of turbine at low speeds, the reverse is true at high speeds. The fact remains, however, that this type can be made to show good efficiency at high speeds, providing the re-directing chambers are properly arranged for high-speed work.

It must be admitted that a Riedler-Stumpf rotor has the advantage over the Curtis rotor in regard to rotation losses, for the reason that the vanes or buckets are undercut down in the rotor. As a result it does not produce the same fan action and there is only one set of buckets, whereas in the Curtis type there are two and sometimes three rows of buckets. It is admitted that the Curtis wheel

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has a considerable fan action, especially in the inactive part of the rotor when only partial admission is used, which is the case with the small turbines under consideration.

It must be admitted, of course, that the Curtis principle is better adapted for large powers and also for condensing operation where it is necessary to handle large volumes of steam. This is not the subject-matter of this paper, therefore I do not think that the author is justified in giving the impression that the Curtis principle is better adapted than the Riedler-Stumpf for small non-condensing turbines.

The author refers to the elimination of certain types of turbines since Mr. George A. Orrok's paper on Small Steam Turbines was presented in 1909. When Mr. Orrok's paper was presented, the Terry, Sturtevant and Bliss turbines were on the market. Since that time the Bliss turbine has been given up by its manufacturers, for the reason that they gave up the turbine business and not because they substituted another type. He refers to the fact that the Terry Company has recently developed machines on the Curtis principle, which indicates that they are abandoning the original Terry machine; whereas, as the writer understands it, the Terry is still used on small sizes, the Curtis principle being used on larger or condensing turbines only. Therefore, with the exception of the Bliss Company, the turbines of the Riedler-Stumpf principle that were being manufactured in 1909 are still in existence, proving that this principle must have some merit.

There is no question but what the author is correct when he states that the so-called flexible coupling cannot sufficiently take care of misalignment and also that bedplates cannot be commercially designed that will stay true from test plate to foundation. It is a comparatively easy matter, however, to line up a turbine with its driven members and it seems to the writer that this is more a question of education than a question of adapting a design to eliminate this feature, thereby getting into other possible troubles. Some difficulty has been experienced in the past because of the fact that engineers have assumed that it was not necessary to realign a turbine and driven apparatus. This is especially true if it was received by them mounted upon a self-contained cast-iron base and connected by means of a flexible coupling. As stated above, this is a question of educating the erecting and operating engineers, and experience seems to prove that engineers are now realizing the necessity of keeping high-speed apparatus in perfect alignment. Experience has

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also shown that after a turbine is once lined up, it will maintain its alignment indefinitely, providing, of course, that it has a suitable foundation.

The author brings out the fact that the companies who are manufacturing the complete apparatus do not have to contend with the same difficulties that are experienced by companies who furnish only a part of the apparatus. It is usually the case that the former have a preference with the engineers for the principal reason that the opportunity of shifting responsibility in case of trouble is eliminated.

The majority of designing and operating engineers seem to agree that it is more desirable to have a turbine rotor, or any other high-speed apparatus for that matter, mounted between two substantial bearings rather than to have it overhung. There is no doubt, however, that the overhung construction is cheaper, will not weigh as much and will occupy less space. The primary consideration in machinery for auxiliary service is reliability. Experience has shown that overhung elements are more sensitive to trouble than elements supported between two bearings. The manufacturer, however, who builds a two-bearing overhung outfit has a decided advantage over a concern that builds a machine which is not self-contained or a machine not complete in itself that must be connected to another machine which is also not complete or self-contained. The question of alignment is bound to be very important, for this alignment refers to internal clearances which necessitate the attention of experienced engineers.

An overhung element must of necessity find its field limited for the reason that the greater proportion of auxiliary drives are gear-driven, and this overhung idea lends itself better to direct-connected apparatus.

The author's idea of a Suggested Code of Practice is something that would certainly be advantageous not only to the manufacturers but to the ultimate users, but, as he explains, in order to apply this idea it would be necessary for every last manufacturer to adopt and adhere to the scheme in order to make it a success. The question is, whether or not manufacturers are ready to get together at this time.

A. G. CHRISTIE (written). The writer's paper on The Present State of Development of Large Steam Turbines, presented to the Society in 1912, ended with some paragraphs on the Trend of Tur-

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bine Development. It was stated there that the combined type of turbine would probably be widely adopted, particularly embodying a Curtis element; that blade speeds would be increased, and that increased efficiency would be obtained through a close study of the action of steam in nozzles, blades and casings; that simplicity of construction would be a leading consideration, that the field of the steam turbine would be greatly extended by the further development of gearing, and that the cost of manufacture would be the final determining factor in future development.

Mr. London's opportune and valuable paper seems to verify these suggested developments to a remarked degree, though he takes exception to the geared turbine. I am inclined, however, to take rather a different view of efficiency from that which he presents, though possibly my view may not be consistent with commercial considerations.

The war is bringing home most emphatically to our American people the need of economy. To the engineer this means getting the greatest number of B.t.u. in useful work from each pound of coal burned. The days of cheap coal are fast passing, and with every dollar added to the cost of a ton of coal, the gain from the use of economizers increases. Hence, great impetus will be given to the installation of such equipment and to water-treating systems which will insure economical operation of such economizers.

Now, with economizers in a plant the feedwater need be heated only to 100 instead of 210 deg. fahr., where feedwater heating by exhaust steam is now used. Hence, under such conditions less exhaust steam will be required; and when steam-driven auxiliaries are preferred to motor-driven units, their economy will be closely scrutinized. It may then be desirable to pay a little more for the more economical turbine auxiliary.

Improvement of design is not wholly inconsistent with decreased cost of manufacture. In fact, we have reason to expect our designers to improve their designs with increased knowledge of steam performance and blade materials, and at the same time to cheapen their product.

The small steam turbine usually employed in driving auxiliary machinery does not require much attention as a rule. It would therefore seem that the class of labor employed in looking after auxiliaries should not be a prime consideration in determining the efficiency of the turbine, as Mr. London would lead us to believe. Still he is quite correct in insisting on simplicity and durability.

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Mr. London's discussion of alignment is very timely and deals with a point that has been a source of great annoyance to purchasers of small turbines. It is to be hoped that manufacturers will take steps at once to finally overcome these difficulties, particularly in those cases where all equipment is not supplied by one party.

I agree with Mr. London in regard to the unreasonable demands by some engineers for numerous guarantees on each small unit that they buy. I have often felt that these men lacked data in regard to turbine performance and used their specifications as a means of drawing this information out of the manufacturers. On the other hand, manufacturers are very reluctant to give out such data as a matter of general instruction and the average engineer has rather vague ideas of what actual performance should be expected from small steam turbines. It would therefore seem that the demands of engineers for guarantees would be simplified if manufacturers would publish such data and let engineers become better acquainted with turbine performance under varying steam- and back-pressure condition and speeds.

Mr. London has argued very vigorously for standard ratings of turbines. On a previous occasion I have urged before the Society the desirability of fixing certain standards for rating steam turbines. I do not believe that we can ever establish a fixed standard. It would be most desirable, however, to decide whether the normal rating should be at maximum load or at 15 per cent under that load. I propose to bring this matter before the Power Test Committee at its forthcoming meeting.

J. L. Moore (written). Mr. London's statement of the types to which the various turbines mentioned belong would be rather confusing to any one not familiar with the history of the development of the steam turbine.

There are three principal original types of steam turbines, the Parsons, the Rateau and the Curtis, to which may be added the Terry type and the Westinghouse single-stage type.

Any turbine built (and a few that are not built) in this country at the present time, both large and small, can be classified under one of the above types, or as a combination of two of them.

Such a classification would be in accordance with that which follows:

Curtis: General Electric Co., De Laval (single-stage), Moore (single-stage), Steam Motors Co.

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Parsons: Westinghouse (large turbines), Allis-Chalmers (large turbines)
Rateau: Kerr, Ridgway, Wilkinson
Curtis-Rateau: De Laval (multi-stage), Moore (multi-stage), Terry (multi-stage)
Curtis-Parsons: Westinghouse (large turbines)
Terry: Terry, Sturtevant, Dake (not built), Bliss (not built)
Westinghouse: Westinghouse (single-stage), Wait (Hill Pump Co.)
Kerr Pelton Wheel: No longer built.

The classification of the present Kerr ("Economy") turbine as an original type is misleading, as this turbine is of the Rateau type, consisting of a series of single-pressure stages. The original Kerr turbine, designed by Mr. C. V. Kerr in 1904, was a multi-stage turbine consisting of a series of single-pressure stages with a steam Pelton wheel in each stage. This turbine is no longer built, having been abandoned in favor of the Kerr "Economy" type, which was designed by the writer about ten years ago. This turbine consists of a series of single-pressure stages, each stage having a set of nozzles and a single wheel, and is therefore of the Rateau type. No claim has ever been made, so far as I am aware, that this turbine was an original type. The distinctive feature of this turbine is the casing design which is split vertically, and the diaphragms or separators between stages are integral with the outer cylindrical portion of the casing.

Mr. London's statement that the Moore turbine is a modified design of the Kerr turbine is erroneous and misleading, for the reason that the Moore single-stage turbine is of the Curtis type, while the multi-stage machine is of the Curtis-Rateau, a combined type. The mechanical details of the casing of the Moore multi-stage turbine are radically different from those of the Kerr "Economy" turbine as the diaphragms separating the Rateau stages are set into grooves in the exterior casing, which is in one piece instead of divided vertically into sections.

The Terry is an original type, unless perhaps the Stumpf (a German design) may have been designed previous to it. It is interesting to note that the Terry Company is now building a combined Curtis-Rateau type, presumably to get better economy than could be obtained with the original type. The Westinghouse single-stage type as built in small sizes by this company is also an original type, and was, I believe, designed by Mr. R. N. Ehrhart about 15 years ago.

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M. NUSIM (written). Turbine development and progress have been very largely influenced by a demand for higher efficiencies, and this is also true so far as small units are concerned.

The Curtis-Rateau turbine, a composite type consisting of a first-stage wheel having two moving rows of buckets followed by a number of stages having a single bucket row per wheel, has been adopted very extensively for large units of all sizes, but by a proper selection of speed it is also being applied for sizes below 1000 hp. for either condensing or non-condensing turbines. This proper selection of speed is often accomplished by the use of reduction gearing, so that standard speeds for modern units of capacities below 1000 hp. vary between 5000 and 7000 r.p.m., depending on size. With such speeds, and also with a proper selection of the number of stages, steam economies are possible with small units which were formerly obtained only with large turbines.

J. A. MACMURCHY[1] (written). In Par. 45*b* Mr. London states that auxiliary apparatus frequently does not receive very good attention, and for that reason the design should be very simple and the machine very durable. I do not think that it can be emphasized too strongly that auxiliary apparatus should be extremely simple in design, so that it can be easily understood by the class of men who will care for it. Relay mechanisms and governing devices which are not direct and very simple should be avoided, as also any device which may require somewhat delicate adjustment. Even more important than this, however, is the question of reliability in operation. It is absolutely imperative that the turbines driving auxiliaries shall be such that there will be no question whatever of their operating continuously. I quite agree with the author that simplicity and reliability of operation are vastly more important than high thermal efficiency, but a skillful designer should be able to obtain the necessary simplicity and reliability, and at the same time a very high efficiency. Efficiency and reliability are not by any means incompatible.

In Par. 48 the author states that forced lubrication is impracticable in small machines for general auxiliary purposes. This has not been my experience, and in later designs the firm with which I am connected is arranging to provide oil pumps for every size of turbine except in a few extremely small lighting sets where ball

[1] Engineer Small Turbine Dept., Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

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bearings are used. The necessary oil pump and oil passages will doubtless add slightly to the initial cost of the turbine, but the advantages fully justify the expenditure. Even in quite small turbines it has been my experience that the addition of at least a small and very simple oil cooler is also justified.

In Par. 50 the author briefly discusses the necessary characteristics of the governor and governor valve, but I feel that he has not sufficiently emphasized the necessity of the governor being relatively very powerful; that is, for a given percentage of speed variation it should exert strong pull on the valve stem. The governor being such an extremely important element, it should receive the same ample lubrication as that provided for the bearings. This lubrication should not be dependent upon the operator for any care.

I am very glad to note the author's somewhat general condemnation of the so-called flexible coupling. With the possible exception of a flexible shaft, which cannot always be provided for, I do not believe that there is such a thing as a flexible coupling for high-speed apparatus. Some couplings are of course better than others, but my experience is that it is better to design the machine so that flexible couplings will not be necessary.

In Par. 55 I note that the Steam Motors Company is building a turbine which is supplied only with one bearing and a solid coupling for connection to the driven apparatus from which one bearing has been removed so that a two-bearing unit is obtained. This is extremely interesting, but my experience has been that the shafts of the ordinary pump and blower are much too light for direct connection to a turbine in this manner, as in many cases the critical speed will be found to be below the running speed, and often so near the running speed as to cause trouble. In geared sets this is quite permissible because of the slow speeds at which the pumps and blowers usually run, and the greater ruggedness of the apparatus.

In Par. 65 the author expresses the opinion that the usual speed-variation requirements are too exacting, and while my experience shows that regulation within 2 per cent is obtainable with entire stability and no tendency to hunt, at the same time I do not believe there is any necessity for so close regulation, and in fact, in most cases believe it to be quite undesirable.

I am quite interested in Par. 69, in which the author discusses the advisability of adoption of a maximum rating standard. The purchaser, in ordering a turbine, should specify the steam pressure which will be available at the throttle and the power which will be

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required. The manufacturer of the turbine should not be required to estimate how much this should be deviated from, and if he furnishes a turbine which meets contract conditions, it should be considered satisfactory.

I do not entirely agree with the author in Par. 74, for there is no reason why efficiency and reliability need necessarily be separate; although it may be true that efficiency will slightly increase the cost.

In Par. [4] of the Appendix it is recommended that for operating conditions up to and including 550 deg fahr. cast iron will be satisfactory in all steam passages. In my opinion it would be much better to specify the maximum superheat at which cast iron can be used, the temperature due to the steam pressure being comparatively unimportant. When the superheat exceeds 125 deg., cast iron should not be used where the castings are large.

In Par. [6] of the Appendix it is recommended that turbines not connected to electric generators be tested before shipment to 20 per cent above normal speed, and that generator sets be tested to 10 per cent above normal speed. I feel that generator sets should also be tested to 20 per cent above normal speed.

In Par. [7] of the Appendix there are enumerated a number of permissible variations from contract conditions under which the units should carry full load, but I cannot see why this should be necessary except in the matter of allowing for some moisture in the steam. If the purchaser desires that the turbine shall carry its full rated load with 90 per cent of the steam pressure which he ordinarily has at the throttle, he should specify this lower pressure; similarly, if he desires that the turbine should carry its full rated load with 1 lb. greater back pressure than that which he expects to have, he should quote this higher back pressure. In other words, the purchaser should best know the conditions under which he wants the turbine to be able to carry full load, and he should specify these.

Par. [8] of the Appendix I understand to be a recommendation that steam-consumption guarantees be given at full load only, and for one set of operating conditions. While I sympathize with the latter clause, I feel that it is often desirable to give the water rate at, say, half load, for in many cases this is important.

In the Appendix, Par. [9], it is recommended that the machine be considered as having met its guarantees if the steam consumption on test be within 5 per cent of the guaranteed figures. I am at a loss to understand what possible advantage there can be in this

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5 per cent leeway. With a clause of this kind in the specifications, bidders would merely deduct 5 per cent from their expected performance, and nobody is deceived except possibly the purchaser. It would be very much better to hold the manufacturers to specific water rates and expect them to have sufficient margin in their guarantees to take care of the variations in machines.

I quite agree with the author's recommendation that an exhaust relief valve be considered merely as a signal valve. I do not, however, agree with his recommendation that a stop valve be not furnished by the manufacturer for each turbine. Some manufacturers use their stop valve as the emergency valve which is controlled by the emergency-stop governor, and this is quite an excellent arrangement because the working condition of this valve can be tested at any time; and, after all, the throttle valve of any engine is no unimportant adjunct. To exclude the stop valve from the specifications will put these manufacturers at a slight disadvantage in bidding. Turbines driving boiler-feed pumps and forced-draft blowers should, in my opinion, be furnished with a speed-regulating governor so that at least the speed of the machine will be controlled should the pressure-regulating device become inoperative. It is so extremely important that these auxiliaries should not shut down that the additional cost of this extra governor is quite justified. The same is true of circulating-pump drives, except in the case of marine sets, where the suction is submerged; and there, because of the necessity for extreme lightness, the design of the unit becomes somewhat special.

In Par. [18] of the Appendix the author recommends that oil rings also be furnished on machines designed for forced lubrication. I can see no possible advantage in this requirement, and these bearings can be made much better if they are not complicated with oil rings.

HERBERT B. REYNOLDS (written). The author states that high thermal efficiency is unnecessary in the small turbine if all the exhaust steam is used. This is true if the exhaust steam is used for heating or in manufacturing processes where any deficiency in the exhaust steam will have to be made up by the use of live steam. However, in the case of a power station where the exhaust steam from the auxiliary turbines is used for heating the feedwater, the steam consumption of the small turbines plays an important part in the efficiency of the power station. It is true that the feedwater heater recovers all of the heat in the exhaust steam, but it does not recover the boiler losses which are incurred during the generation of the steam, and which vary directly with the amount of steam.

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In order to illustrate the importance of considering the steam consumption of steam-driven auxiliaries, assume that bids have been received from two different manufacturers for a turbine-driven blower unit of a given capacity. The data and calculations may be tabulated as follows:

Bids	A	B
Price	$2500	$3000
Steam consumption, lb. per hour	3500	3000
Comparison of Bids		
Cost of the heat in the coal necessary to generate the required steam per hour, assuming that coal costs $0.30 per 1000 lb. of steam	$1.050	$0.900
Value of the heat recovered by the feedwater heater per hour, assuming a boiler efficiency of 70 per cent and neglecting the heat absorbed by the turbine	$0.735	$0.630
Net cost of operating the blowers per hour due to the unrecovered boiler losses	$0.315	$0.270
Net cost of operating the blowers per year due to the unrecovered boiler losses, assuming the blowers to be in operation 4000 hours per year	$1260	$1080
Fixed charges per year at 12 per cent	300	360
Total cost per year	$1560	$1440

Thus it will be seen that the cheaper turbine would be the more expensive one in the long run.

In order to make these calculations complete, the heat absorbed by the turbines should be considered. However, in view of the fact that the amount of this heat is so small and that it is approximately the same for both cases, as shown in Fig. 13, it was neglected in the example given above.

C. P. Crissey (written). There is no doubt that in many cases needlessly severe guarantees are requested by purchasers of small turbines, and the author has done a service in bringing this to general attention.

Any code of practice to be successful must first provide that the turbine meet the requirements of service, and not be primarily for the convenience of the manufacturer.

Regarding steam consumption, as a rule, one guarantee point is sufficient; that is, the ultimate operator is fully protected by a guarantee at a single load, one speed and the given steam and exhaust conditions. If other load points are required they should not go below one-half load; quarter-load guarantees should not be required.

When guarantees are given on a condensing turbine, they should not be asked for under non-condensing conditions.

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The purchaser is justified in requiring that certain loads be developed under abnormal conditions which are bound to occur. For instance, the author states that the output is reduced about 20 per cent when the steam pressure drops 10 lb., with an increase of 2 per cent moisture and a rise of 2 lb. back pressure. An experienced purchaser will state the load required and the average conditions of operation at which an economy guarantee is desired, and then specify that the load shall be carried at somewhat poorer conditions which he foresees are liable to occur in ordinary operation. If the purchaser is inexperienced the code should protect him by specifying that the maximum load must be developed if the steam pressure drops a certain percentage, this drop being sufficient to allow for a change in quality or reasonable change in exhaust condition. To meet this requirement the turbine should be supplied with a hand valve opening additional nozzle sections, which, when open, are under control of the valve gear. The cost of the addition is well worth while as a simple matter of insurance.

While economy guarantees on a condensing turbine operating non-condensing should not be required, it is quite reasonable in some instances to demand that a certain fraction of the rated output be developed non-condensing, the purchaser bearing in mind that the demand should not be greater than necessary to safeguard the actual operation of his plant.

It would also be well for a code to prohibit bearing temperatures of 250 deg. fahr.

There is absolutely no reason why the power requirements of pumps and blowers should not be known just as accurately as the outputs of turbines, and they are so known in properly conducted organizations.

It is quite possible to obtain satisfactory operation with a two-bearing unit having a small overhung turbine wheel, but it is a type which, in the nature of things, should be built by manufacturers of combined units. The case is entirely similar to the rigid-frame and three-bearing units commended by the author when both parts of the unit are built in one shop. When built by different parties the proposition is, as he says, entirely different. Whether the driven machine is generator, blower or pump, if trouble develops, neither one of the manufacturers or an arbitrator can determine at which door the fault lies.

There are very good reasons why units having four bearings and a coupling have not been more generally superseded by two- or

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three-bearing sets. This is best illustrated by turbine-driven pumps. In this case a multiplicity of pumps must be driven by a given size of turbine, and on the other hand a certain size of pump must be capable of being driven by several sizes of turbines to meet the demands of various services and customer's requirements. In many cases where economy is of prime importance gears must be interposed between the turbine and pump. It is therefore apparent that an overhung turbine with two bearings or a three-bearing set is an obstruction to producing sets upon a manufacturing basis. Practically every set is a new design that requires careful calculation to prevent trouble from critical speeds or deflection of the wheel which will cause rubbing of the buckets. All this is true when both machines are produced in the same shop. If manufactured in different shops, lengthy correspondence is required to determine whether the pump manufacturer can increase the size of shaft through impellers and bearings to carry a heavier turbine wheel, etc. As no customer is going to wait upon such determinations, it follows that the average agent and some manufacturers will take a chance, with the result that the customer receives an untried and, in many cases, thoroughly unsatisfactory unit.

Customers should guard themselves against two- or three-bearing units that have not been operated with the same distances between bearings, the same diameter of shaft and the same loads upon the shaft, especially when the responsibility is divided between two manufacturers.

CHARLES W. DAKE[1] (written). In enumerating the various types and makes of steam turbines, the statement is made that the Dake turbines are either no longer on the market or are not seriously competitive. The Dake turbines are being manufactured by the Pyle-National Company, Chicago, Ill., and there have been built and are in successful operation 22,300 of them, aggregating some 70,000 hp. These turbines are of the single-stage impulse type made under the Charles W. Dake patents, substantially all of which are used in connection with turbo-generator units. More than 80 per cent of the electric headlights in operation on steam locomotives today are driven by turbo-generators manufactured under the Dake patents.

THE AUTHOR. Mr. Bentley states that Fig. 7 does not correctly indicate the true path of steam through the Terry turbine. This is

[1] The Pyle National Co., Chicago, Ill.

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perfectly true and the author referred to this figure only as a conventional view, fully appreciating the fact that the reversal in a bucket of this type is 180 deg.

Mr. Bentley states that, other things being equal, the amount of energy that a rotor will extract from the steam varies directly as the angular reversal. He further argues that the angular reversal in this type of turbine being 180 deg., the amount of energy to be expected will therefore be double that of a turbine of the Curtis type. I would like to point out in this connection, however, that while the steam is reversed through 180 deg. in the plane of the path of the steam, the *effective* angular reversal is by no means 180 deg., as will be seen from Fig. 14. This angular reversal should be multiplied by the cosine of the angle a. If we take an extreme case and assume the jet to be in the position indicated by the dotted lines, in other words, radial, there would be no propulsive effort in the steam irrespective of the fact that there is a reversal of 180 deg. So that it is evident that while we have the maximum possible reversal with this type of turbine, this must be multiplied by the cosine of whatever angle is used.

It is true, as Mr. Bentley states, that the fan action in the Terry or Riedler-Stumpf type of wheel is less than in the Curtis. I feel that this is more than counteracted by the increased friction due to the length of the path of the steam through the buckets of the two types.

While Mr. Bentley concedes that the so-called flexible coupling cannot sufficiently take care of misalignment and that bedplates cannot be commercially designed that will stay true, he contends that it is an easy matter to line up a turbine with its driven members and that the whole question is merely a matter of education. I think the arguments presented by Professor Christie and by Mr. MacMurchy are sufficiently forcible to show that this question of alignment is really a much more serious proposition than Mr. Bentley would have us believe.

I must take exception to Mr. Bentley's broad statement that overhung elements are more sensitive to trouble than elements supported between two bearings. Is this not purely a matter of stresses and the design of shaft, etc.? We have accepted for years the overhung flywheel in reciprocating engines as good practice, so with a properly designed turbine wheel and shaft I cannot see wherein this same practice in turbine engineering should be condemned. Mr. Bentley seems skeptical regarding the possibility of adopting the Suggested Code of Practice and states that every last manufacturer must ad-

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here to this scheme in order to make it a success. This point is exactly what I tried to bring out. Electrical engineers apparently were able to get together on this point and I do not see why this same coöperation could not be satisfactorily worked out with the builders of small turbines, particularly when we look upon the benefit the electrical codes have been to all electrical manufacturers.

Referring to the class of labor employed in looking after auxiliaries, Professor Christie states that this should not be of prime consideration in determining the efficiency of the machine. It must be considered, however, that the last degree of efficiency cannot be obtained without certain complications to the machine such as high speeds or automatic nozzle control, both of which are undesirable where the type of labor employed to look after such apparatus is unskilled.

Referring to Mr. Moore's discussion regarding the correct names of the types mentioned in the paper, I fully agree with Mr. Moore

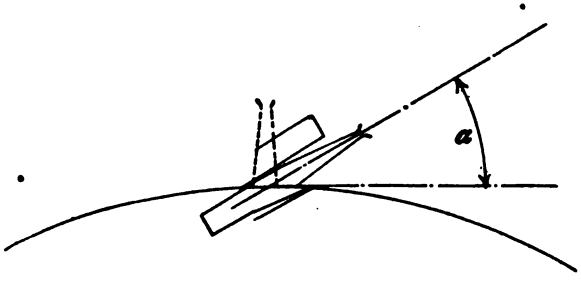

FIG. 14 ANGULAR REVERSAL OF STEAM IN TERRY TURBINE BUCKET

that the Kerr turbine is of course of the Rateau type, but in my paper I tried to keep to the designation of types used by Mr. Orrok, as will be noted from Par. 4 of the paper.

Regarding the Terry, I agree with Mr. Moore that this is substantially an original type as it contains a special form of reversing chamber, which is the fundamental principle of this type of machine. However, I do not agree with Mr. Moore that the Westinghouse single-stage machine is an original type. The original principle of this machine dates back as far as 1864 (Perrigault, Farcot, etc.). See Mewes, Dampfturbinen, 1904.

I was very much pleased to read Mr. MacMurchy's criticism of the arguments advanced against the use of the so-called flexible coupling and his statement that it is better to design a machine eliminating this uncertain factor. But I must take exception to his argument against the overhung wheel when connected to pumps, which is

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based on the assumption that the critical speed of the average pump is such that the overhung rotor will increase the operating troubles.

In connection with this point I would like to bring out that the critical speed of any rotor is a function of deflection. In other words, the greater the deflection, the lower the critical speed. By placing an overhung turbine wheel on to a pump shaft the direct tendency is to reduce the deflection of the pump shaft, thereby increasing the critical speed; so that it would appear that the overhung element in this instance has an advantageous effect rather than the contrary.

I think Mr. MacMurchy has rather misinterpreted my meaning when he states that efficiency and reliability must necessarily be separate. I agree with him that it is possible to make two machines having the same diameter of wheel, one having a high efficiency and the other a very poor efficiency, but the idea I intended to convey in my paper was that, assuming the same degree of skill to be employed throughout in designing any particular machine, any increase in efficiency over a certain design of single-stage wheel must be obtained either by increasing the diameter of the wheel, thereby increasing the stresses, etc., or by employing a multiplicity of stages.

Referring to his criticisms regarding permissible variations in contract conditions, Mr. MacMurchy is of course perfectly correct in stating that the purchaser should best know the conditions under which he wants the turbine to be able to carry full load, but if his experience agrees with mine, he must know that although this is correct in theory, it is seldom found to work out in practice.

Mr. MacMurchy does not agree with the author that a stop valve should not be included. One of the main reasons why it was suggested that this be a separate item was that the stop valve in small machines is very rarely placed next to the turbine and it is often found more convenient to place it somewhere in line some little distance away from the turbine governor valve. Regarding the use of oil rings with machines fitted with forced-feed lubrication, I cannot help feeling that the little extra expense this incurs is a good insurance that the bearings will always receive a certain amount of oil in case of starting up, shutting down, or failure of the oil pump at any time.

Mr. Reynolds takes exception to the statement that the heat from the exhaust steam, while being utilized, does not overcome boiler losses with an inefficient turbine auxiliary. This is perfectly correct, but in general practice the small difference in heat absorbed by one machine and another, even with a widely varying degree of efficiency, will bring the point brought out by Mr. Reynolds to an almost negligible quantity in practice.

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No. 1607

BAGASSE AS A SOURCE OF FUEL

By E. C. Freeland,[1] Baton Rouge, La.
Non-Member

The heating value of one pound of average dry Louisiana bagasse is found by experiment to be 8300 B.t.u., and, despite a high moisture content of about 50 per cent, it is therefore a valuable fuel. While in former years not much attention was paid to the drying of bagasse before burning it, many authorities now claim that a great saving can be effected by such a procedure. The heating value of this important fuel to the sugar industry, as influenced by the high moisture content, and the benefits of preliminary drying are discussed at length, and notes are included on devices employed by various sugar houses in its use for steaming purposes.

THE use of bagasse, or megasse, as it is sometimes called, as a source of fuel, dates from the earliest periods of cane-sugar manufacture. Even before vacuum pans came into use, the sugar manufacturer was wont to burn the sun-dried, or even the green, bagasse under the open kettles. When steam was introduced into the sugar factory as a means of heating the cane juice and syrup, bagasse came to be burned under the boilers as a result. The first boilers designed for bagasse burning differed very little from the coal-burning boilers of that time. As more modern improvements were introduced into cane-sugar manufacture, the methods of burning bagasse were also improved upon, so that at the present time very efficient bagasse-burning installations have been perfected. A few of these will be described in a subsequent portion of this paper.

2 Some of the questions one might ask, when seeking information about this particular fuel, are: Of what value is bagasse as a fuel? How does it compare with coal or oil? What is its composition? It may be well to discuss a few of these points.

3 Chemically, bagasse consists mainly of a tough fiber, sugar or sucrose, glucose and other reducing sugars (by a reducing sugar

[1] Louisiana State University.

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers. Received Honorable Mention, Student Prize Contest, 1917.

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is meant one that will reduce Fehling's solution), and water. The fiber content ranges from 30 to 50 per cent; the sucrose from an almost negligible quantity to as high as 10 per cent; and the water from 40 to 65 per cent; the other constituents occur in such small amounts that they may be disregarded. Its composition varies greatly, according to the method and effectiveness of milling the cane, good milling resulting in a bagasse of low sugar and water content that is very suitable for burning. In Louisiana the fiber content averages about 40 per cent and the moisture about 53 per cent, the remaining 7 per cent being mainly sucrose.

METHODS OF CALCULATING THE FUEL VALUE OF BAGASSE

4 There are several methods employed in calculating the fuel value of bagasse. In this country Prof. E. W. Kerr's formula is in general use. According to one of his bulletins the fuel value of one pound of bagasse is calculated as follows:

5 The heating value of one pound of dry bagasse, by experiment, is 8300 B.t.u. Assume that the moisture content of a bagasse is 48 per cent, and that this bagasse is burned in a furnace the stack temperature of which is 500 deg. fahr. One hundred per cent minus 48 per cent equals 52 per cent dry matter in bagasse. Fifty-two per cent multiplied by 8300 equals 4316 B.t.u. in the dry bagasse. Assume the temperature of the bagasse as 80 deg. fahr. Then the water in the bagasse will have to be raised from 80 deg. up to its boiling point (212 deg. fahr.) and then vaporized before the bagasse can be completely burned. The calculations for the heat necessary to vaporize this water are as follows:

212 deg. − 80 deg. = 132 deg.; 500 deg. − 212 deg. = 288 deg.

Heat necessary to raise the water in 1 lb. of bagasse to the boiling point = $0.48 \times 1 \times 132 = 63.4$ B.t.u.

Heat necessary to vaporize the water in 1 lb. of bagasse from a temperature of 212 deg. = $0.48 \times 1 \times 970 = 465.6$ B.t.u.

Heat necessary to superheat vapor from 212 deg. to 500 deg. = $0.48 \times 1 \times 288 \times 0.5 = 69.1$ B.t.u., where 0.5 is taken as the specific heat of superheated steam.

Heat lost in the water = $63.4 + 465.6 + 69.1 = 598.1$ B.t.u.

Net heating value of 1 lb. of bagasse containing 48 per cent moisture = $4316 - 598.1 = 3717.9$ B.t.u.

6 Prinsen Geerligs, the noted authority on cane-sugar manufacture, has introduced the following formula for calculating the fuel value of bagasse according to its composition:

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Heating value in B.t.u. of 1 lb. bagasse = (8550 × per cent fiber) + (7119 × per cent sucrose) + (6750 × per cent glucose) − (972 × per cent water).

The results obtained by using this formula compare very well with the results obtained by burning the fuel in a calorimeter. The one point in favor of using Professor Kerr's formula is that it does not require a complete chemical analysis of the bagasse, which is absolutely necessary when employing the Geerligs formula.

7 It has been found that the average Louisiana bagasse has a heating value of about 8300 B.t.u. per pound of dry bagasse and of from 3620 B.t.u. gross when containing 56.7 per cent moisture to 4800 B.t.u. gross when containing 42.8 per cent moisture. The

TABLE 1 COMPARISON OF HEATING VALUES OF CUBAN AND LOUISIANA BAGASSE

Variety of bagasse	Extraction, per cent	Moisture, per cent	Fiber, per cent	Heating value, B.t.u. per lb.	
				Total	Net
With 80 per cent juice extraction on weight of cane					
Cuban	80	32.8	60	5628	4092
Louisiana	80	42.8	50	4816	3345
With nearly equal moisture contents					
Cuban	75	42.6	48	4807	3335
Louisiana	80	42.8	50	4816	3345

(For a more extended table of this kind, see La. Bulletin 117, p. 45)

net heating values are respectively 2200 and 3350 B.t.u. It is thus seen that the heating value per pound ranges between wide limits according to the moisture content. In all of the above 5 per cent was allowed for radiation and no excess air present. The heating value of Cuban bagasse approaches that of Louisiana very closely for a given moisture content, but for a given per cent extraction on weight of cane the heating value of a pound of Cuban bagasse is greater than that of a pound of Louisiana bagasse, due to the lower moisture content of the Cuban product. The results given in Table 1 are typical.

8 The Louisiana varieties of sugar cane yield from 400 to 580 lb. of bagasse per ton of cane, or on an average of 20 to 30 per cent of the total amount of cane ground. In a 1000-ton house (1000

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tons every 24 hours) this would amount to about 480,000 lb. a day, or from 19,500 to 21,000 lb. per hour.

9 One pound of bagasse will evaporate from 2 to 3½ lb. of water "from and at 212 fahr." Assuming coal and fuel oil to have respectively heating values of 14,000 and 19,000 B.t.u. per lb., then, from 4 to 6 lb. of bagasse are equivalent to 1 lb. of coal and from 43 to 65 lb. equivalent to 1 gal. (about 7.6 lb.) of oil.

10 Professor Kerr, in his latest tests at Louisiana sugar houses, found that the bagasse from one ton of cane generated from 1.16 to 1.44 boiler horsepower for 24 hours. Thus the bagasse from a 1000-ton house for 24 hours will generate from 1160 to 1440 boiler hp. during that period of time. It would require about 60 tons of coal per day to do the same work, assuming that the coal equivalent of the bagasse from 1 ton of cane is 120 lb. It is thus seen that bagasse plays an important rôle as a source of fuel in the sugar house.

METHODS USED IN DRYING BAGASSE

11 In former years not much attention was paid to the drying of bagasse before burning it. It was the custom either to sun-dry it or feed it to the furnaces in a wet condition, just as it came from the mills. Of later years, however, many devices have been put into use in order to dry it partially before it is burned.

12 In Mauritius, apparatus known as "secheries" have been put into use for this purpose. They consist of a chamber near the chimneys, in which is arranged a system of conveyor belts alternately traveling in opposite directions. The flue gases go through this apparatus and their waste heat is utilized to dry the wet bagasse carried by the belts. In countries where labor is cheap and fuel high, as in some parts of Egypt, other devices whereby the bagasse is conveyed around the smokestack and smokebox of the boilers by means of a screw-like conveyor, have come into use to remove part of the moisture from the bagasse.

13 A very efficient bagasse drier has been designed by Professor Kerr (La. Bulletin 128), which is in the form of a tower-like structure. The bagasse is conveyed to the top and falls downward over a series of inclined shelves placed opposite each other. The dried bagasse is conveyed from the bottom of the drier to the furnaces. The furnace gases are used to dry the bagasse and are conveyed to the bottom of the drier and pass upward, the hottest gases coming in contact with the driest portion of the bagasse. An induced-

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draft system is employed, the fan being placed near the top of the drier.

14 Of late, especially in large factories in Cuba and Hawaii, stokers are being put into use to dry bagasse. These stokers are mainly of the step-grate type, some with front feed and others with double feed, and the bagasse is fed at the top or upper back part of the stoker in the same manner as coal. They have proved to be very efficient as a means of drying bagasse, as well as in regulating its combustion.

15 As to the economy of bagasse drying, many authorities claim that a great saving can be effected by drying this fuel before it is fed to the furnace. This has been proved as a result of many experiments. Noel Deerr states that in Mauritius he found that bagasse entering a secherie with 50 per cent of moisture would leave containing only 35 per cent; this amount of water corresponds very closely with the evaporation of half the original moisture. In a calculation of the heat lost in the flue gases he found that 565 B.t.u. per lb. of bagasse were carried away in the associated water: a saving of half this would be 282 B.t.u., reducing the heat carried away in flue gases from 1675 to 1393 B.t.u.; or expressed as a percentage on the total heat of 1 lb. of bagasse, the loss in the flue gases is 30.4 per cent as compared with 36.6 per cent loss calculated for wet bagasse. Professor Kerr says that in Louisiana 16 per cent of the total heat generated by the combustion of 1 lb. of bagasse is required to evaporate the moisture present. About 14½ per cent of the moisture in Louisiana bagasse was removed by drying it, and the dried bagasse had a heating value of 55 per cent greater than the wet bagasse. This means that a saving of over 2½ gal. of oil will be effected per ton of cane ground. In a factory grinding 60,000 tons of cane per season this means a saving of about 154,000 gal. of oil, or 3670 bbl., which, at $1.25 per bbl., means a saving of $4587.50 per season.

BOILER FURNACES FOR BURNING BAGASSE

16 As has been said before, bagasse was formerly burnt in furnaces very similar to those used for burning coal. During recent years, however, many improvements have been made along this line. In present practice furnaces of the Dutch-oven type are very widely used. Boilers of all types, including those of the Scotch marine type, are used in connection with the Dutch-oven type of furnace.

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17 Table 2 gives the types of boilers in use at a few Louisiana sugar houses. Other types in use in Louisiana (given in Bulletin 117, La. Expt. Station) are: Babcock & Wilcox; Cook water-tube (vertical tubular); Climax water-tube (vertical tubular); and various types of boilers of the "half" and "full" Dutch-oven types.

18 In Demerara the Abel type of furnace is used in connection with the standard types of boilers. By using this furnace the heated gases of combustion pass three times along the boiler. The essential difference between the Dutch-oven and Abel type of furnace is in the size of the combustion chamber, which in the latter type is much larger.

19 In Louisiana the combustion chambers of sugar-house boilers are generally large. Where oil is burned in connection with bagasse, which is the case in many houses, there is a tendency to make the

TABLE 2 TYPES OF BOILERS USED IN LOUISIANA SUGAR HOUSES

House	Type of boiler
Angola	Horisontal return tubular, with Dutch oven and small draft fan
Cinclare	Scotch marine, with suspension furnaces and Dutch oven
Poplar Grove	Stirling, with Dutch oven
Adeline	Horisontal return tubular, with large and elaborate combustion chamber
Vermilion	Horisontal return tubular, with Quinn flat-top furnace

combustion chamber smaller since the burning oil causes a better combustion of the bagasse, the furnace temperatures being higher when burning these two fuels together than the furnace temperatures obtained by burning either of them alone, if the furnace is of the proper design. It has been shown conclusively (La. Bulletin 131) that it is better to burn bagasse alone in a Dutch-oven furnace than to burn it with oil in this same type of furnace. At some of the new installations some of the boilers are designed to burn bagasse alone, the remaining boilers burning oil alone. This is considerably better than the old method of having all the boilers equipped with Dutch ovens and burning both bagasse and oil under them.

20 The grate surface should be small in furnaces used for burning bagasse, as the rate of combustion is high, sometimes as high as 300 lb. per hr. per sq. ft. of grate surface. This corresponds to about 20 boiler hp. per sq. ft. of grate surface. Some of the recently installed 500-hp. boilers in the tropics have only 25 sq. ft.

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of grate surface. Small grates require less manipulation and care in order to prevent excessive air losses than is the case with large grates, there being less danger of portions of the grate being uncovered, etc. The amount of grate surface per boiler hp. also varies with the amount of moisture in the bagasse — the less moisture there is, the smaller the grate surface can be made. In Professor Kerr's recent tests the highest rate of combustion was at Adeline (225 lb. bagasse per hr. per sq. ft. of grate surface), while the lowest was at Vermilion (85 lb. per hr. per sq. ft.), corresponding to about 15 and 6.5 boiler hp. per unit area, respectively. It is probable that a mean between these two sizes would be good practice.

TABLE 3 DATA ON BOILER TESTS AT LOUISIANA SUGAR HOUSES

Item	House		
	Adeline	Angola	Vermilion
Bagasse burnt per hr., lb.	3777 to 5614	2299 to 3441	3586 to 3687
Moisture in bagasse, per cent	45.4 to 53.0	53.1 to 58.6	46.3 to 47.0
Grate surface, sq. ft.	25	28.89	42
Heating surface, sq. ft.	2500	1512	2450
Equivalent evaporation from and at 212 deg. per hr., lb.	8636 to 13,093	2197 to 6476	9131 to 9469
Bagasse burnt per hr. per sq. ft. of grate surface, lb.	151 to 225	79.6 to 119	85.4 to 87.8
Steam pressure, lb. per sq. in. abs.	97 to 119	87.8 to 106	108.7 to 109.8
Quality of steam, per cent	98.3 to 99.8	98.5 to 99.6	98.5 to 98.7
Draft in flues, in. of water	0.464 to 0.634	0.300 to 0.487	0.417 to 0.434
Equivalent evaporation from and at 212 deg. per lb. of bagasse, lb.	2.13 to 2.35	1.36 to 1.90	2.48 to 2.64
Efficiency of furnace and grate, per cent	*a* 56.83 to 64.61 *b* 63.17 to 71.93	*a* 48.96 to 60.32 *b* 55.26 to 67.63	*a* 61.15 to 66.65 *b* 67.65 to 73.81

21 It is the practice in Louisiana to use systems of forced or induced draft as the source of air supply. Bagasse contains a large amount of air, but when burned on a small amount of grate surface with a high rate of combustion it requires a high draft. When, however, it is burned in furnaces having a large combustion chamber and a large surface, air in nearly all cases is supplied in great excess, which lowers the efficiency of the boiler and grate. Where forced draft is used in Louisiana, the general tendency is to supply air in great excess.

22 In order to present comparative figures on boiler tests at Louisiana sugar houses, a partial list of results is given in Table 3, which shows in each case the highest and lowest values obtained.

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23 In calculating the efficiencies in Table 3 the following methods were used: Efficiency a = heat leaving in steam per lb. wet bagasse divided by net heating value of 1 lb. of wet bagasse [gross heating value per pound minus (heat necessary to vaporize moisture present in it plus heat necessary to raise to stack temperature)]. Efficiency b = heat leaving the steam per lb. wet bagasse divided by [net heating value per pound (same as above) plus heat required to vaporize moisture formed by the combination of the hydrogen and oxygen in the fuel]. It is probable that the latter method of calculating efficiencies is more suitable for making comparisons where there is a considerable variation in the quality of bagasse.

24 In conclusion, it may be said that, although many recent improvements have been made in the methods of burning bagasse, there are yet many fields open along this same line. Methods of regulating the air supply, improvements in furnaces and driers and utilization of the heat in the waste flue gases are some of the problems being worked upon by the sugar-house engineer of today, with a view to conserving as much as possible the heat furnished by this most valuable by-product of the sugar house.

DISCUSSION

David Moffat Myers (written). My most recent experience in connection with bagasse burning occurred during seven weeks in Cuba last winter, where I was retained to investigate and report upon the conditions of boiler-plant economy in six sugar mills. I submit the following observations relating in particular to my investigation of a mill in the eastern part of the island, near Manzanillo Bay, with a capacity of 3750 tons per 24 hours.

In this section of the island the fiber content of the cane is only about 10 per cent, whereas in some other parts it runs as high as 12 per cent, thus giving in the latter a bagasse of greater heating value, while the mill requirements for steam are less owing to the lesser quantity of juice extracted. Consequently the mill supplied with cane of the higher fiber content has a great advantage in respect to economy in the use of auxiliary fuel.

In Cuba, in a perfectly designed and properly balanced sugar mill, i.e., where the exhaust steam produced is no greater than the demand for it, and where all the condensation from modern multiple-effect evaporators is returned to the boilers, the by-product bagasse is sufficient to supply all the steam when all departments of the plant

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are working in harmony. But where these conditions do not obtain, and there are numerous examples, auxiliary fuel in the form of wood, oil or coal must be burned.

In Cuba, wood is the most common auxiliary fuel and the cheapest in cost per million B.t.u., although the connected labor is greater than with either of the other fuels.

There is no trouble whatever in obtaining a very high-grade combustion with bagasse, even with very crude methods and furnaces. When the supply of bagasse was coming regularly and no wood was used in the furnaces, the CO_2 ranged from 10 to over 17 per cent. When wood was fired in with the bagasse, especially by some of the methods commonly employed, the furnace efficiency was immediately reduced to a degree indicated by a CO_2 content of from 3 to 6 per cent.

By changing the method of firing the wood with certain furnace alterations, a great improvement was obtained both in more uniform steam pressure and in a substantial reduction of the amount of auxiliary fuel required.

From the standpoint of the mill owner the cost of the auxiliary wood fuel — formerly about $300 per day — was a matter of only secondary importance. But the difficulty in maintaining uniform working steam pressure was of vital importance, since the inability to do so was reducing the normal capacity of the mill by an amount of grinding equivalent to $500,000 per year in output of sugar.

Stated briefly, the causes for this loss due to inability to hold steam were as follows:

1 Irregularity in feeding the furnaces, due largely to ignorant labor without white-man supervision. Supervision was installed and a large improvement immediately effected.

2 Wrong method of firing wood with furnaces ill-adapted to the purpose. This was corrected and furnaces improved, with an additional improvement in steam pressure and substantial reduction in auxiliary fuel.

3 Draft regulation entirely wrong. Plan was prepared for convenient regulation by uptake dampers to control fires and steam production.

4 Grate surfaces with natural draft burned 300 lb. bagasse per sq. ft. per hour when clean after Sunday shutdown, but clinker on furnace walls grew so rapidly that by the middle of the week the grate area would become so restricted that the capacity of the boilers was seriously

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reduced and formed a chief factor in the inability to hold steam. This trouble was corrected in the new furnaces I designed and installed by using larger grate surface. This resulted in ability to obtain boiler capacity at all times.

5 Owing to the surplus of exhaust steam in this badly balanced plant and to other causes relating to the design and operation of the whole mill, sufficient condensation was not available for boiler feed. Consequently, raw water had to be used as a make-up supply. This water was from wells, and its analysis showed it to be of the most detrimental character for boiler feed that I had ever found. The boilers, as a consequence, were covered with heavy scale, pitted badly and were constantly springing leaks.

The effect on fuel economy and steam production need hardly be described.

The remedy recommended was a lime-soda process of purification, filtration and storage for the raw water, and this system has been specified, purchased, and will soon be installed.

Other changes were recommended and are being installed, and there is no doubt that when the improvements are all in effect the production saving of about half a million dollars per year will be accomplished.

In further regard to the combustion of bagasse, there is one point that is likely to be overlooked unless the combustion engineer is familiar with the operation of sugar mills. A bagasse-burning boiler plant is subject to a very critical disadvantage not imposed on any other kind of a boiler plant. There is no storage supply of fuel *at the furnaces* available for instant use when occasion demands. When the boiler pressure begins to drop rapidly, the natural method employed in coal-fired steam plants is to increase at once the feeding of the fuel and the supply of air to the furnaces. This method is not applicable with the usual design of sugar-mill boiler-house equipment. The bagasse carriers keep an approximately uniform stream of the fuel moving along over the furnace tops as the mills supply it, and it is fed directly from the carriers through adjustable gates and feeders to the furnaces. Any surplus bagasse travels to the end of the conveyor, where it discharges in a pile on the ground. This pile forms the only available storage of fuel.

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Consequently, when a shortage occurs or when additional steam is quickly drawn from the boilers, there is no adequate method of meeting the emergency. The result is likely to be a serious drop in steam pressure, causing longer cut-off of mill engines and a further increase in the demand for steam. The excessive time required to pitch from the surplus pile into the conveyors, added to the time consumed by the travel of this bagasse to the furnaces, renders this method of storage of little or no avail. Therefore, unless auxiliary fuel, such as oil or coal, is immediately fired as the steam pressure begins to fall, the effect is so bad that at times it becomes necessary to shut down the mills to raise steam to working pressure.

This problem, in my opinion, is more important than that of drying the bagasse, which must necessitate a complication of plant not desirable under the difficult conditions of ignorant labor which must be depended upon in Cuba.

In fact, the problem of bagasse burning cannot successfully be considered merely as a combustion problem, although, of course, that forms one of the factors. But other factors enter more importantly in an efficiently operated sugar mill. Some of these have been touched upon (in the beginning of this discussion), and they include considerations relating particularly to the scientific design of the whole mill combined with its operation.

If there is trouble and delay at the mills, the bagasse supply is interrupted and the best furnace design is of no avail; unless intelligent supervision of the regulation of bagasse feeding and of dampers and cleaning of fires is provided, scientific boiler and furnace equipment helps but little; if a shutdown occurs at the evaporators, the mills are badly affected.

The matter of boiler efficiency in a sugar mill is inflexibly connected to, and affected by, the operation of the production functions of the entire mill. Consequently an efficient boiler plant becomes largely a by-product of these other conditions relating to the general management of the mill and the harmonizing and correlating of its functions.

Such very large savings can be accomplished along these lines, given a well-designed boiler plant, that such an apparatus as a bagasse dryer would not generally be favorably regarded by plant owners unless its installation and operation could be effected at low cost and its design were such as to require little or no attention and virtually fireproof.

In the operation of the plant referred to, upon which I conducted

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a large number of tests on combustion and evaporation, when the CO_2 ran above 16 per cent there were usually found considerable amounts of CO. In one test for which a heat balance was computed the CO produced a loss equal to about 12 per cent of the available heat in the bagasse as fired.

The corresponding flue-gas analysis was 14 per cent CO_2, 3.5 per cent O_2 and 3.7 per cent CO.

The extent to which the CO_2 could be raised without formation of CO depended upon the furnace design, the larger combustion chambers making possible the higher values of CO_2 without loss due to CO. With some of the settings tested, 15 per cent CO_2 could be maintained with but an occasional trace of CO.

When bagasse is burned at high rates of combustion (200 to 300 lb. per sq. ft. of grate surface per hour), the time required for complete combustion is lengthened so that extra large combustion chambers must be employed if a high CO_2 without CO is to be obtained. Owing to the large volatile content of this fuel, the completion of combustion occurs at a point much later in its travel than in the case of coal under equally favorable conditions. Consequently, with horizontal tubular boilers, the combustion in many cases under forced conditions will not be completed until the gases enter the tubes at the rear end. A consequence of this is a comparatively high temperature of gases in the combustion chamber, thus rendering a large tube surface of especial value for absorbing as much as possible of the remaining heat.

The rapid filling up of combustion chambers by deposits of ash which fuse to hard clinker forms an added reason for providing very large combustion spaces in the design of furnace and setting. In the case of vertical-pass water-tube boilers, the boiler should be set sufficiently high and with such arrangement of arches and baffles as to complete the combustion before the gases enter the spaces between the tubes.

Following are a few brief notes relating to the available heating value of Cuban bagasse, weight of bagasse per boiler hp-hr., etc., selected from my report on the plant referred to.

Fuel Value of Bagasse and Boiler Hp. Obtainable

Assume mill to grind 300,000 arrobas[1] of cane per day with 75 per cent extraction, giving 75,000 arrobas of bagasse per day. Then, bagasse per hour = 3120 arrobas = 78,000 lb. = 39 tons of 2000 lb.

[1] One arroba = 25 lb.

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Available heating value of bagasse calculated for this plant, B.t.u. per lb. as fired	3,800
B.t.u. per boiler hp-hr. (= 34½ × 970.4)	33,479
B.t.u. to generate 1 boiler hp-hr. at 60 per cent efficiency	55,798
Pounds of bagasse to generate 1 boiler hp-hr. = 55,798/3,800	14.7
Bagasse available per hour when grinding 300,000 arrobas of cane per day, lb	78,000
Boiler hp. from bagasse when grinding 300,000 arrobas of cane per day = 78,000/14.7	5,310
Boiler hp. from bagasse when grinding 250,000 arrobas of cane per day	4,430
Boiler hp. from bagasse when grinding 200,000 arrobas of cane per day	3,533

The heat value of the bagasse was computed in two ways, first by formula, and second by an assumption of dry heat value (which I have confirmed by bomb-calorimeter tests) and calculating the heat-moisture loss. The results agree within 2 per cent. Both computations follow.

Method 1. Calculation from this mill's analysis of February 19, 1917, with B. & W. formula, assuming according to Noell Doerr that $G = S/10$. Formula:

$$\frac{8550\,F + 7119\,S + 6750\,G - 972\,W}{100} = \text{B.t.u. per lb.}$$

Percentage analysis from laboratory:	
H_2O (W)	47.05
Fiber (F)	44.55
Sucrose (S)	6.81
	98.41
Glucose (G, assumed = $S/10$)	0.68
Total	99.09

Other gums and substances not shown by analysis.

Substituting these values in the formula gives:

$$\frac{381{,}000 + 48{,}400 + 4{,}500 - 45{,}700}{100} = 3882 \text{ B.t.u. per lb.}$$

Method 2. Assume 8300 B.t.u. per dry lb. ("Steam," Babcock & Wilcox Co.) and 47 per cent moisture. Then total heat = 0.53 × 8300 = 4399 B.t.u. per lb. as fired. With flue temperature = 512 deg. fahr. and temperature of bagasse = 82 deg. fahr., heat to evaporate moisture =

$$0.47\,[(212 - 82) + 970 + 0.48(512 - 212)] = 585 \text{ B.t.u.}$$

Total heat per lb. as fired	4399 B.t.u.
Heat to evaporate moisture	585 B.t.u.
Available heat per lb. as fired	3814 B.t.u.

This checks to within 2 per cent of the value obtained by Method 1.

Available heat per lb. of combustible =

$$\frac{3814}{100 - (0.47 + 0.01)} = 7340 \text{ B.t.u.}$$

(Ash assumed at 2 per cent.)

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H. L. HUTSON (written). The author's paper starts a train of thought which it is interesting to follow, namely: What will our descendants do when the supply of stored sunshine in the shape of coal and oil is exhausted and they have to grow their own fuel?

Taking Mr. Freeland's figures and assuming for Louisiana an average crop of 20 tons of cane per acre, we find that this would yield 5 tons of bagasse, which would have a fuel value equal to about one ton of coal.

Roughly, a ton of cane costs as much as a ton of coal, so that the cost of growing bagasse as fuel under present conditions would be twenty times that of coal. This is assuming that the juice with its sugars is thrown away or considered as a by-product. If, however, the heat value of the sugar and molasses and the 10 to 15 per cent of the cane left in the field is taken into account, a little figuring will show that we can grow a fuel at about eight times the cost of coal.

Our descendants will, no doubt, use their fuel more economically than we do and may, in many cases, get more than eight times as much useful work out of it. In fact, in China the ratio is no doubt larger than this, as they will cook their food in an oven heated by a bundle of stems of cotton or other crop, and then sleep on top of the oven by night and use it as a seat by day.

In parts of the tropics, alcohol made from molasses is cheaper than gasoline, and the efficiency of this fuel used in an internal-combustion engine is several times better than that of ordinary fuel used with a steam engine.

THE AUTHOR. I wish to thank Mr. Myers for his valuable discussion, especially for that portion dealing with the causes for inability to maintain the steam pressure when burning wood. This inability to hold steam pressure is not confined to sugar houses burning wood as auxiliary fuel, but is also encountered in some houses using oil in connection with bagasse, even when the bagasse supply is uniform; and the same causes for inability to hold steam when burning wood in connection with bagasse will also apply to cases when oil is used.

As Mr. Hutson says, our descendants will, no doubt, have to grow their own fuel when the present supply is exhausted. Even at the present time the problem of an ever-decreasing supply is becoming more and more serious, and unless some means for the more economical utilization of fuel is brought into use, it will not be many years before they will be forced to look to other sources for their fuel.

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No. 1608

THE COOLING OF WATER FOR POWER-PLANT PURPOSES

RESULTS OF AN EXPERIMENTAL INVESTIGATION AND DESCRIPTION OF AN ADJUSTABLE SPRAY NOZZLE

By C. C. Thomas, Baltimore, Md.
Member of the Society

This paper presents the results of an extended experimental investigation into the conditions governing the cooling of the condensing water of power plants by means of spray ponds. This investigation involves determining the efficiency of the cooling process under varying conditions of pressure at the spray nozzles, the temperature of the water to be cooled, the power required to circulate the water, the height of sprays above the pond surface, the effect of wind velocity on the cooling range, etc., and the work has resulted in a large collection of data, much of which is presented in the text.

As a result of his experiments the author has developed a new form of spray head or nozzle which is so adjustable that the film of water discharged may be broken into either a uniformly fine spray, a mist, or a large number of small drops, as desired. This method of spraying is particularly applicable to low-pressure work, a pressure of 10 in. of mercury giving an exceedingly fine spray, and 8 in. usually sufficing.

Probably the most completely controlled means for cooling water in large quantities is found in the forced-draft cooling tower. The newly developed spray head, however, provides for control of the system in a manner which, while somewhat less complete than in the case of the cooling tower, yields results comparing very favorably with those for the tower, and can be installed and operated at a much lower cost.

THE purpose of the work here described was to ascertain the conditions governing the cooling of water by means of spray ponds. This involved determining the efficiency of the cooling process under varying conditions of pressure at the spray nozzles, the temperature of water to be cooled, the power applied to the pumps, the height of sprays above the pond, etc. The work has resulted in a large collection of data, part of which is presented here, and also in the development of the new form of spraying device described.

EXPERIMENTAL WORK

2 The experiments were made on the pond shown in Fig. 1, which is part of the power plant and laboratory equipment of The

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Johns Hopkins University, Department of Engineering. The pond is 35 ft. in diameter and 4 ft. deep and was designed with special reference to experimental work as well as to cool the condensing water for a 50-kw. Buckeyemobile fitted with a surface condenser. The water is ordinarily sprayed through one spray head, or nozzle, of the new type described in this paper, but some of the tests were made with nozzles of other types. A motor-driven centrifugal pump with 4-in. suction and discharge sends the water through the condenser tubes and to the spray head, as shown in Fig. 1.

3 The pressure at the spray head or other type of nozzle was in all cases measured by a mercury column connected to the entrance of the spraying device, and the recorded pressures are for that point.

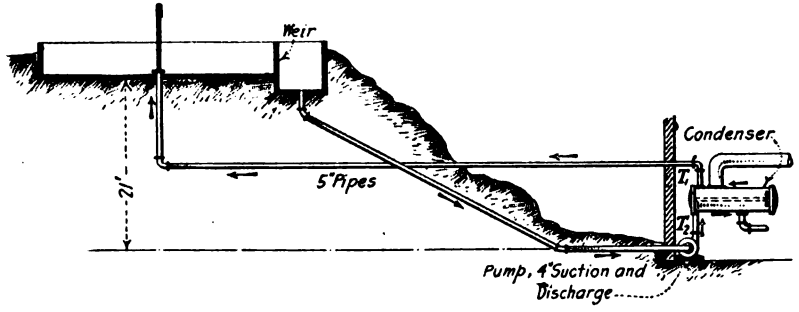

FIG. 1 COOLING SYSTEM USED IN THE EXPERIMENTS

Wind velocity was measured by a standard anemometer, and the humidity by a wet-and-dry-bulb sling psychrometer. The amount of water circulated was measured by a 10-in. weir, as shown in Fig. 1, fitted with a micrometer hook gage.

4 About six hundred tests have been made, mostly with the new type of spray head, shown in Figs. 2, 3, and 4, but tests Nos. 11 to 18, 86 to 91, and many others not reported here were made with three sizes (3-in., 2-in., and 1-in.) of nozzle having spiral cores, as shown in Fig. 5. The data given in the Appendix are representative of the tests.

5 It was desired to ascertain, among other things, the effect of placing a wire fly-screen cylinder about the spray head, and many of the tests were so made, as shown in the tables and in Fig. 6. Under some conditions this screen seemed to improve the efficiency, but in general it was not found necessary or worth while to use.

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EFFICIENCY OF COOLING PONDS AND TOWERS

6 The efficiency E of a cooling pond or tower may be expressed as the ratio between the cooling actually produced, $T_1 - T_2$, and that which would have resulted from cooling the water down to the wet-bulb temperature T_w. Thus

$$E = \frac{T_1 - T_2}{T_1 - T_w}$$

T_1 and T_2 being the temperatures of the water before and after cooling, respectively. A perfect spray-cooling device would be one

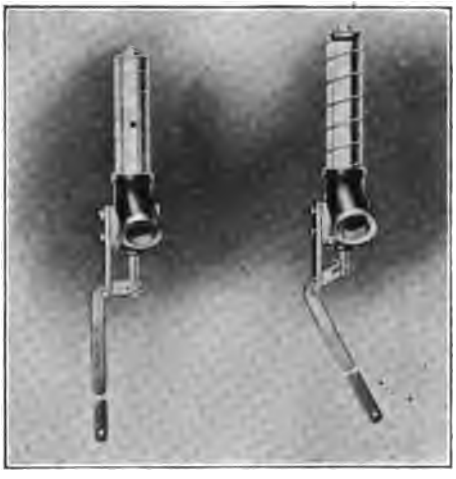

FIG. 2 THOMAS ADJUSTABLE SPRAY HEAD, CLOSED AND OPEN

capable of subdividing the water so that evaporation would take place at T_w, and to an extent such as to lower the temperature of the remaining liquid spray to that temperature. The extent to which this is approached in practice is indicated by the figures in the tables of data.

7 The curves in Figs. 7 and 8 show variation of efficiency of the adjustable spray head with variation of pressure and with variation of capacity, respectively, for three initial temperatures, namely, for $T_1 = 98$, 105 and 125 deg. fahr. These results were obtained by adjusting the spray head to suit the weather conditions existing at the time. From these curves the cross curves on Fig. 9 were drawn,

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for use in predicting the cooling range to be expected from a given set of conditions. This may be done as follows:

8 From these curves the efficiency to be expected for any given initial temperature T_1 and for any given pressure at the nozzle, may be found.

9 If an initial temperature of water, T_1, and an average air temperature, T_a, and humidity be assumed for the locality of the cooling pond, the expected cooling range may be worked out.

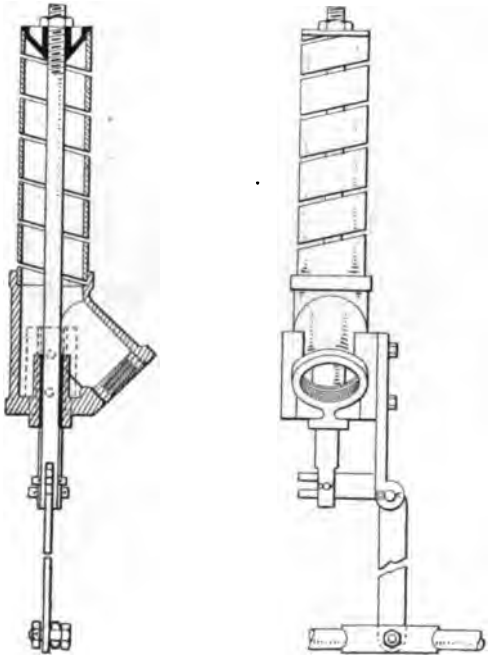

FIG. 3 SECTION AND ELEVATION OF THOMAS ADJUSTABLE SPRAY HEAD

10 For example, if $T_1 = 115$ deg. and $T_a = 70$ deg. and if humidity = 0.55, then, from a humidity table, $T_a - T_w = 10$ deg. or $T_w = 70 - 10 = 60$ deg., and

$$T_1 - T_w = 115 - 60 = 55 \text{ deg.}$$

Let the pressure at the nozzle be 10 in. mercury. From the curves, the efficiency to be expected in cooling water from 115 deg. by spraying it with 10 in. mercury pressure at the nozzle is

$$\frac{T_1 - T_2}{T_1 - T_w} = 0.70$$

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and the cooling range will then be

$$T_1 - T_2 = 0.70\,(T_1 - T_w) = 0.70 \times 55 = 38.5\,\text{deg.}$$

11 It is of interest to observe the wide variation of efficiency shown in Fig. 10 which takes place during a long period of operation when no attempt is made to adjust the spray head so as to obtain

FIG. 4 THOMAS ADJUSTABLE SPRAY HEAD IN OPERATION

FIG. 5 NON-ADJUSTABLE NOZZLE WITH SPIRAL CORE

uniformly good results. The tests yielding these points cover about a year. The heavy black circles indicate results from the non-adjustable nozzles, while the others refer to the adjustable spray head when operated under widely varying weather conditions, pressures, and temperatures of water, without any attempt to obtain high efficiency. It will be noticed that with the non-adjustable nozzles, such as shown in Fig. 5, the pressures used are high and capacities very low as compared with those for the adjustable spray head.

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12 Fig. 11 shows for a few related tests the variation of cooling range, $T_1 - T_2$, with pressure at the spray head.

13 Fig. 12 shows efficiencies obtained with the water falling upon the bare cement bottom of the pond as compared with those resulting when the pond contained its normal amount of water. These results are rather surprising and it is hoped that further tests may be made to confirm or to controvert them. If a bare pond would serve as well as one containing water, the construction of the pond could be

FIG. 6 THOMAS SPRAY HEAD EQUIPPED WITH WIRE-SCREEN CYLINDER

cheapened since less weight would come upon the foundation and less material would be required for the pond as a whole.

FACTORS INVOLVED IN THE PROBLEM OF COOLING WATER

14 *The loss due to evaporation* during a period of eight days is shown in Table 1. These data are not yet complete, but the average evaporation may probably be taken as about 2.25 per cent. This will, of course, vary with weather conditions, initial temperature of water, pressure at the nozzle, and with humidity. A large number of tests made with water at high and low initial temperatures indicate that 2 to 2.5 per cent per hour represents fairly well the average loss of water, but that it may be as low as 0.5 per cent, and in windy weather as high as 10 or 15 per cent with non-adjustable nozzles.

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In the case of the 40-ft. by 60-ft. pond at Sparrows Point, Md., referred to later, the loss of water per 24 hours is shown by a decrease in height of water level of about six inches. This corresponds to a loss of about 0.31 per cent per hour, and represents average conditions at this pond. This pond is very well protected from wind, and the loss stated is probably smaller than that usually obtaining.

TABLE 1 TESTS WITH ADJUSTABLE SPRAY HEAD, AT LOW PRESSURE AND AT LOW INITIAL TEMPERATURES, TO ASCERTAIN LOSS OF WATER DUE TO EVAPORATION

Test number	1	2	3	4	5	6	7	8
Date, 1917	9-27	9-28	9-29	10-3	10-4	10-5	10-6	10-8
Duration of test, hours	6½	6½	4½	8	8	8	6	8
Hook-gage zero, ft.	1.422	1.422	1.422	1.422	1.422	1.422	1.411	1.411
Hook gage, first reading, ft.	1.593	1.592	1.592	1.577	1.571	1.597	1.598	1.511
Hook gage, last reading, ft.	1.565	1.570	1.582	1.571	1.552	1.584	1.545	1.481
Loss on hook gage, ft.	0.028	0.022	0.010	0.006	0.019	0.013	0.053	0.030
Pressure at nozzle, in. mercury	4.27	6.10	3.00	5.24	6.74	6.23	6.59	5.10
Temperature at inlet, T_1, deg. fahr.	86.0	83.5	84.0	73.9	79.6	81.6	70.3	80.0
Temperature from pond, T_2, deg. fahr.	80.4	77.8	78.0	70.6	73.6	74.3	64.6	70.2
Cooling range, T_1-T_2, deg. fahr.	5.6	5.7	6.0	3.3	6.0	7.3	5.7	9.8
Dry-bulb temperature, T_a, deg. fahr.	75.8	75.7	76.0	69.6	75.2	73.1	59.4	63.5
Wet-bulb temperature, T_w, deg. fahr.	66.6	68.2	66.0	57.1	62.0	61.9	50.1	56.5
Depression, T_a-T_w, deg. fahr.	9.2	7.5	10.0	12.5	13.2	11.2	9.3	7.0
Humidity, per cent	62	70	60	46	47	53	53	65
Loss of water,[1] per cent per hour	2.49	1.99	1.30	0.483	1.59	0.934	4.99	4.11

[1] Average loss of water (8 days), per cent per hour, 2.23.

The average efficiency for the 8 days covered by the above tests is 32½ per cent, and this will be seen to correspond with the 6-in. pressure curve (extended) in the T_1 and efficiency curves on Fig. 9. With such low initial temperatures and pressures this represents the efficiency and cooling range to be expected. The initial temperatures varied from 70 to 86 deg. and the air temperatures from about 60 deg. to 76 deg.

15 *The power required to circulate the water* is shown in Fig. 13 as watts per gallon per minute per degree of cooling from varying initial temperatures. In order to test the accuracy of this curve experiments were made on a pond at Sparrows Point, Md., which is equipped with two sets of nozzles, either of which may be used. One set consists of 42 non-adjustable, spiral-core nozzles, and the other set of 12 of the adjustable spray heads described in this paper. The power required with the adjustable spray heads at Sparrows Point is shown by the point so marked in Fig. 13, the other points being from the Johns Hopkins pond. From this curve the power required to circulate the water in a given case can be estimated, to cover specified temperature and capacity. The power appears to be

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practically independent of the type of spraying device used. The average power required to drive the pump may be calculated from the following equation representing the curve drawn through the experimentally determined points in Fig. 13:

$$P = \left(\frac{100}{T_1}\right)^{3.23}$$

where P = power of the pump motor in watts per gallon per minute per degree fahrenheit of cooling, and T_1 = initial temperature of the water to be cooled, deg. fahr. (not absolute temperature). The cooling seems to be principally dependent upon the energy put into

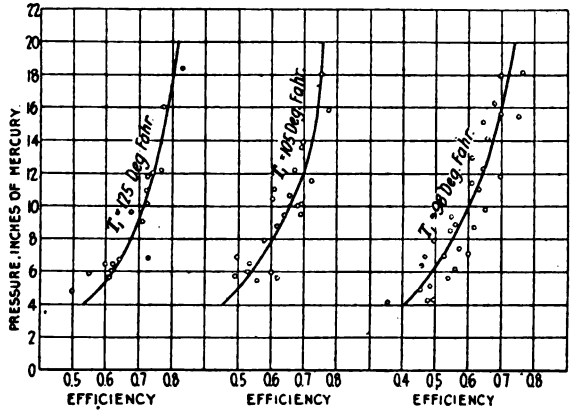

FIG. 7 VARIATION OF EFFICIENCY OF ADJUSTABLE SPRAY HEAD WITH VARIATION OF WATER PRESSURE

forcing the water through some suitable spraying device, and given the requisite energy a great variety of forms of nozzle would yield about equally good results. The operating advantages of the adjustable spray head and its large capacity greatly facilitate keeping the heads clean without shutting down to clean them. It also permits regulation of the spray to suit weather conditions and to minimize loss of water and inconvenience to the nearby buildings due to driftage in windy weather. The amount and cost of piping are comparatively small for the adjustable spray head, since each one will handle from 150 to 250 gal. per min. In general, each adjustable spray head will handle the condensing water for a 50- to 75-kw. plant.

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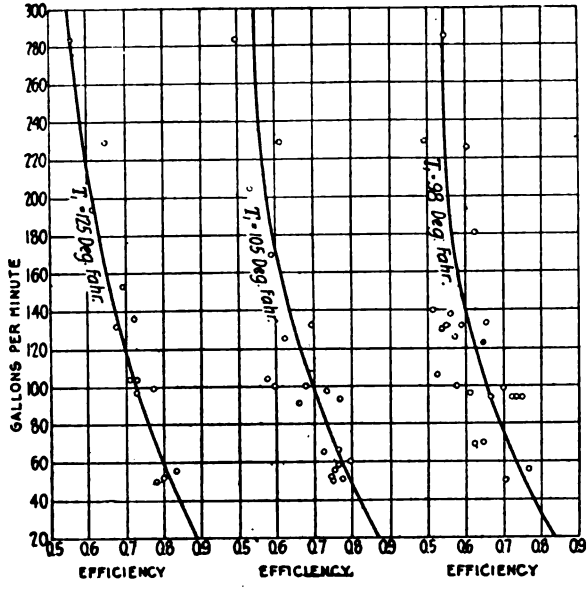

FIG. 8 VARIATION OF EFFICIENCY OF ADJUSTABLE SPRAY HEAD WITH VARIATION OF CAPACITY

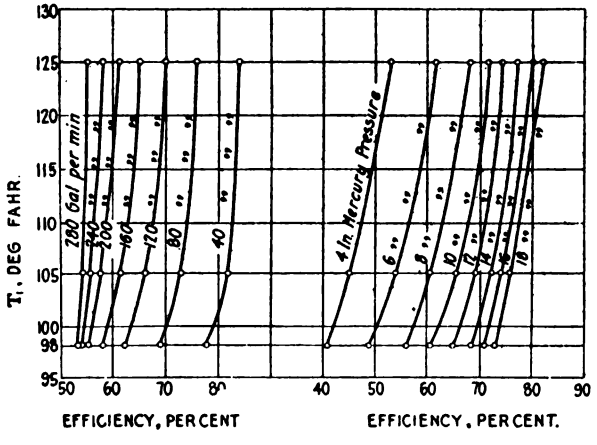

FIG. 9 CURVES FOR PREDICTING COOLING RANGE TO BE EXPECTED FROM A GIVEN SET OF CONDITIONS

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16 *The height of spray nozzles above the surface of the pond* has an important effect upon the cooling of the water. Experiments made not only in the small pond, but in three larger installations, have shown that the nozzles should be kept as low as possible. In the experimental pond heights from 8 ft. down to 3 ft. have been used, and in larger ponds from 6 ft. down to 3 ft. A loss of several degrees, perhaps 8 to 12 deg., results from placing the nozzles high above the pond, which was at first done because it was thought that the long path of the water through the air would result in correspondingly

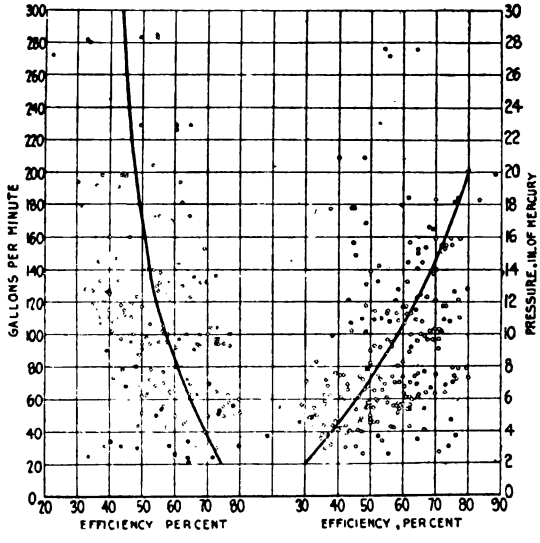

FIG. 10 CURVES SHOWING WIDE VARIATION OF EFFICIENCY WHEN PROPER ADJUSTMENT OF SPRAY HEAD IS NEGLECTED

(Black circles indicate results from non-controlled nozzles)

greater cooling. This is not borne out by experience, however, and is probably due to the following combination of circumstances: First, a given pump, placed in a certain relation to the surface of the pond, will deliver a smaller amount of water to a high level than to a lower level, and this smaller amount will leave the condenser at a higher temperature than did the larger amount of water; second, with a given amount of power at the pump, less energy will be available for breaking up the water if the nozzle is placed high than if it is placed low, and it appears that minute subdivision of the water is more important than is a long path through the air. The higher initial

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temperature of the water, combined with the smaller amount of energy available for atomizing, results in a higher final temperature than would be found if the nozzles were placed more nearly on a level with the pump.

17 *The effect of wind velocity upon the cooling range* is shown in a series of related tests by the curves in Fig. 14, for initial temperatures of 98, 105 and 125 deg., respectively.

18 *Spraying upon a series of superposed inclined cement plates* was tried, and the resulting cooling ranges are shown in Fig. 15, as compared with the cooling obtained without the plates. As was the case when spraying upon the bare bottom of the pond, the plates seemed to produce comparatively poor results, but further tests might well be conducted to test this out further.

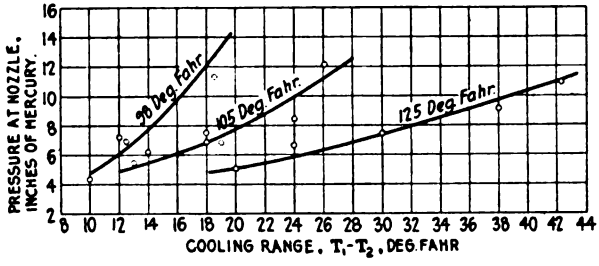

FIG. 11 VARIATION OF COOLING RANGE, $T_1 - T_2$, WITH VARIATION OF PRESSURE AT THE SPRAY HEAD

19 *The cooling range as affected by the amount of water sprayed by a given adjustable spray head* is shown in Fig. 16. As the spiral opening is made wider, the degree of atomization and resulting cooling are of course reduced. This has its advantages, however, as in windy weather very good cooling can be obtained when spraying a very large amount of water per nozzle, and loss of water due to windage can be greatly reduced. Fig. 17 shows the capacity of the adjustable spray head as affected by pressure at the spray head and by width of the spiral opening.

20 It has been found to be very difficult to take account of all the variables involved in the problem of cooling water, and perhaps no one formula will cover the matter completely. It is hoped that further investigation will serve to define the effect of humidity and wind velocity and some of the other variables, and that this paper may perhaps stimulate others to do more complete work than the writer has been able to accomplish.

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21 It has been somewhat surprising to find that very good cooling effect frequently obtains in very humid and even in rainy weather;

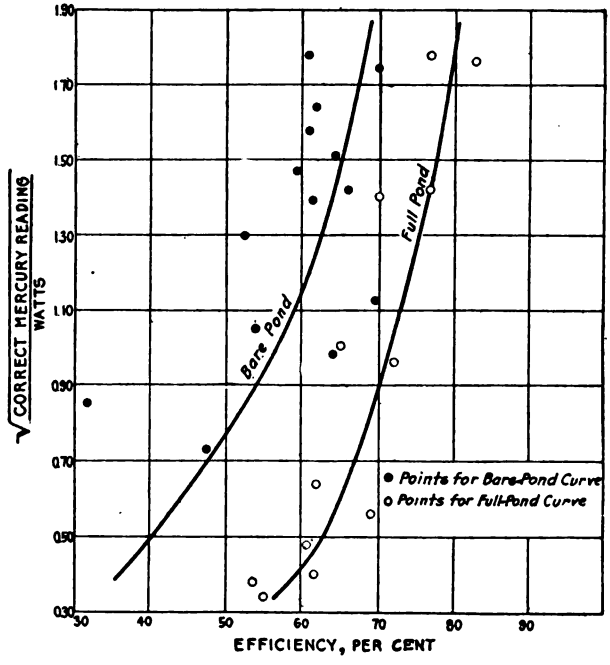

FIG. 12 EFFICIENCIES WITH WATER FALLING ON BARE CEMENT BOTTOM OF POND AS COMPARED WITH THOSE WHEN POND CONTAINS ITS NORMAL AMOUNT OF WATER

and also that cooling effect seems to bear no direct relation to humidity. The cooling effect seems to depend largely upon conduction of heat from the air, and to vary directly with fineness of subdivision of the water particles.

THE AUTHOR'S ADJUSTABLE SPRAY HEAD

22 The adjustable spray head is shown in Figs. 2 and 3. It consists of a cast-iron supporting base containing the water-entry opening and carrying a 3½-in. outside-diameter bronze tube in which is cut a spiral opening of coarse pitch. This opening is cut with a tool placed at an angle of about 60 deg. with the axis of the tube so that the water is thrown upward at this angle. The spiral tube is

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held between the base and a cap which fits the top by means of a central bronze stem which passes down through a close-clearance bushing in the base. This stem is movable and is operated by a

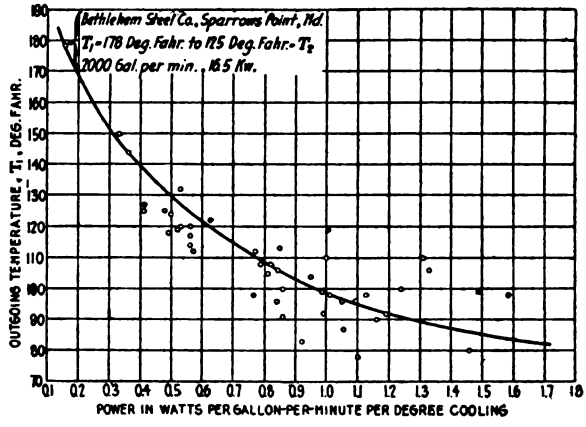

FIG. 13 POWER REQUIRED TO CIRCULATE WATER IN COOLING SYSTEM FROM VARIOUS INITIAL TEMPERATURES

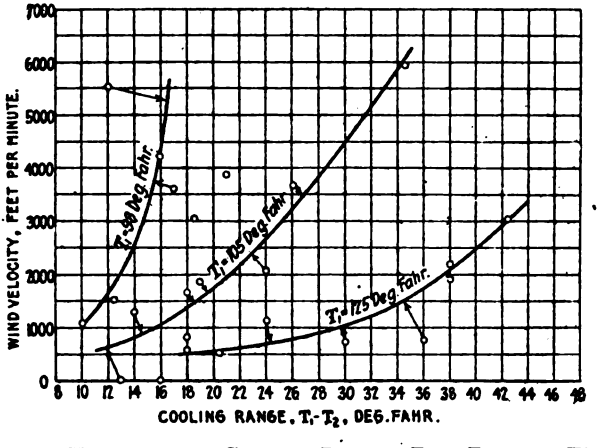

FIG. 14 VARIATION OF COOLING RANGE, $T_1 - T_2$, WITH WIND VELOCITY

bell crank having an extended vertical arm giving accurate control of the position of the stem. The result of the motion is to either increase or decrease the fineness of the film of water as it leaves the

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spray head. When the head is in operation the water is discharged in a continuous sheet in a direction which is inclined upward, due to the angle of the spiral opening. As the water film spreads it becomes thinner on account of its increasing diameter until a point is reached where the surface tension is overcome and the sheet of water breaks into either a uniformly fine spray, a mist, or a large number of small drops, depending upon the size of opening to which the spray head has been adjusted. This principle of spraying a liquid as the result of the spreading of a film of water until it breaks into mist, or spray, or fine drops, is particularly applicable to low-

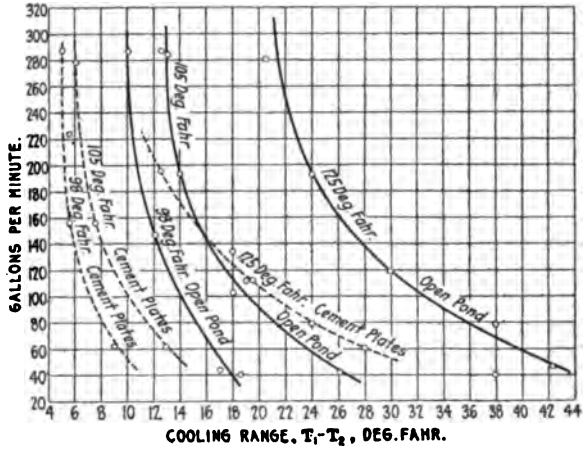

FIG. 15 VARIATION OF COOLING RANGE, $T_1 - T_2$, WITH CAPACITY WHEN SPRAYING ON SUPERPOSED INCLINED CEMENT PLATES AND ON THE OPEN POND

pressure work, and it will be noticed that the pressures used in the experiments described are relatively low, being in general from 5 to 8 in. of mercury. A pressure of 10 in. gives an exceedingly fine spray, and in general 8 in. at the spray head is ample. Of course, the higher the pressure, the more extensive is the cooling, and this is true with all forms of nozzle.

CONCLUSION

23 In conclusion, it is of interest to consider some other methods of cooling water and to compare the results with those obtained from spray ponds. The simplest method is to discharge the water

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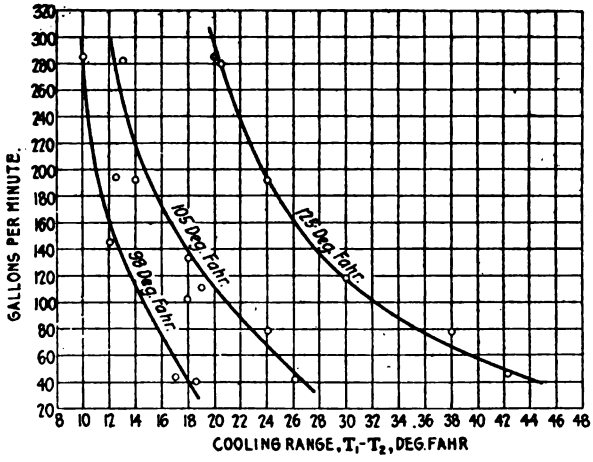

FIG. 16 COOLING RANGE, $T_1 - T_2$, AS AFFECTED BY AMOUNT OF WATER SPRAYED BY A GIVEN ADJUSTABLE SPRAY HEAD

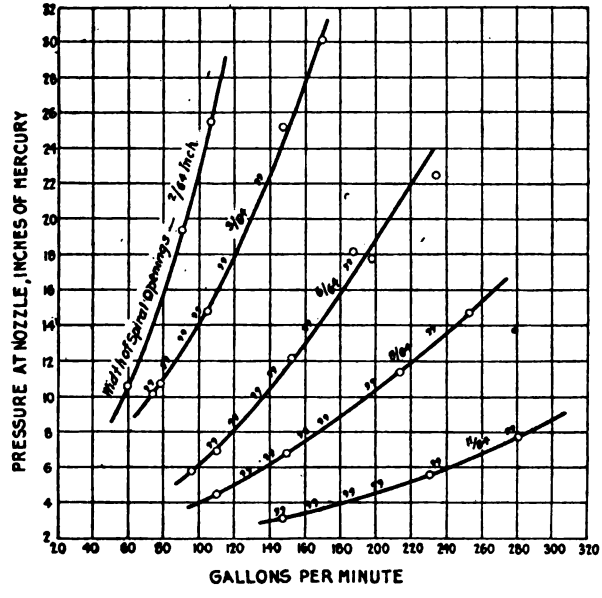

FIG. 17 CAPACITY OF THOMAS ADJUSTABLE SPRAY HEAD AS AFFECTED BY PRESSURE AT SPRAY HEAD AND WIDTH OF SPIRAL OPENING

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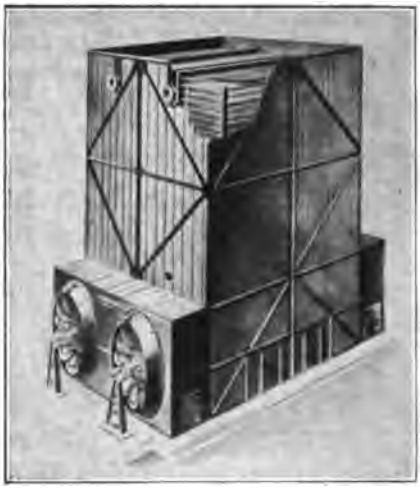

FIG. 18 TYPICAL FORCED-DRAFT COOLING TOWER

FIG 19 COOLING POND WITH ADJUSTABLE SPRAY HEADS FOR STATION OF 2500 KW. CAPACITY

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through a single pipe line to a pond of sufficient area so that the water will be cooled by contact with the atmosphere on the surface of the water. Such a pond must be very large in order to obtain satisfactory results, and in order to reduce the area required it is necessary to add some device by which additional contact of the water with the atmosphere is obtained. Probably the most com-

TABLE 2 RESULTS OF TESTS OF COOLING TOWERS

No. of test	T_1	T_2	T_1-T_2	T_a	Humidity, per cent	T_w	T_1-T_w	Efficiency	Draft	Gal. per min.	Gal. per min. per sq. ft.
C. H. Wheeler Co. Cooling Towers											
1	83	68	15	65	65	58	25	0.600	Natural	3600	2.00
2	124	88	36	82	60	72	52	0.693	Natural	400	1.39
3	130	90	40	82	78	76.5	53.5	0.748	Natural	850	1.42
4	144	80	64	89	49	75	69	0.928	Forced	480	2.81
5	82	73	9	75	37	59	23	0.391	Forced	5000	4.00
6	108	74	34	86	44	70	38	0.895	Forced	1400	2.47
Jenckes Spinning Co. Open-type Towers											
1	85	72	13	64.5	65	58	27	0.482			
2	70	52	18	25	61	22	48	0.375			
3	72	60	12	57	40	46	26	0.462	(Wind 10 mi. per hr.)		
4	66	48	18	37	60	32.5	33.5	0.538			
5	86	68	18	74.3	60?	64.8	21.2	0.850			

pletely controlled means for cooling water in large quantities is found in the forced-draft cooling tower, which is particularly effective because of the regularity with which an air current is brought into contact with water spread out and dropping from properly arranged surfaces. The cost of installation and operation of a forced-draft tower, however, is very much greater than for a spray pond. The newly developed spray head provides for control of the system in a manner which, while somewhat less complete than in the case of a cooling tower, yields results which compare very favorably with those from the tower. Table 2 shows results obtained from tests of several cooling towers, some having forced draft and some natural draft. Fig. 18 shows a typical forced-draft tower and Fig. 19 a cooling pond equipped with adjustable spray heads for 2500 kw. capacity of turbines.

24 The experimental pond shown in Fig. 1 was built in 1914 for the dual purpose of serving the University power plant and permitting investigation of the problems discussed in this paper. The

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writer has had much assistance from others and is particularly indebted to Mr. W. J. Dana, Instructor in Mechanical Engineering, Johns Hopkins University, to Mr. John P. Powell, Superintendent of Gas Engines, Bethlehem Steel Co., Sparrows Point, Md., and to the C. H. Wheeler Mfg. Co., Philadelphia.

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APPENDIX

TABLE 3 TESTS OF THOMAS SPRAY HEAD WITH CYLINDRICAL SCREEN
(READINGS EVERY 15 MIN.)

Test Number	110	111	112	113	114	115	116	117	Avg.
Date, 1916 (A.M.)	9-11	9-11	9-11	9-11	9-11	9-11	9-11	9-11	.....
Opening number	13	13	13	13	13	13	13	13	.....
Height of water on mercury gage, in	66.2	66.5	66.5	66.7	66.6	66.6	67.0	66.8	.....
Height of mercury gage, in	10.9	12.0	12.0	12.2	12.1	12.1	12.5	12.3	.....
Correct height of mercury gage, in	6.03	7.11	7.11	7.30	7.20	7.20	7.58	7.39	7.12
Temp. leaving condenser, T_1, deg. fahr	76	75	74	75	75	75	77	76	75.4
Temp. entering condenser, T_2, deg. fahr	66	67	67	67	67	67	68	68	67.1
Cooling range, $T_1 - T_2$, deg. fahr.	10	8	7	8	8	8	9	8	8.3
Air temperature, T_a, deg. fahr.	67.5	67.5	69	68	67	68	69	69	68.1
$T_2 - T_a$	−2.0	−0.5	−2.0	−1.0	0	−1.0	−1.0	−1.0	−1.0
Dry-bulb temp., deg. fahr	68	68	69	68	68	69	70	70	.....
Wet-bulb temp., T_w, deg. fahr.	61	62	62	61	61	61	62	61	.....
Wind velocity, ft. per min	207	291	152	229	114	269	234	302	225
Wattmeter reading, kw	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
Vacuum, in. mercury	27.5	27.5	27.5	27.5	28.5	28.25	27.75	27.75	27.78
$T_1 - T_w$	15	13	12	14	14	14	15	15	14
$T_2 - T_w$	5	5	5	6	6	6	6	7	6
Efficiency $= \frac{T_1 - T_2}{T_1 - T_w} = E$	0.667	0.615	0.583	0.571	0.571	0.571	0.600	0.533	0.589
Weather	Partly cloudy								

TABLE 4 TESTS OF THOMAS SPRAY HEAD WITHOUT CYLINDRICAL SCREEN
(READINGS EVERY 15 MIN.)

Test Number	118	119	120	121	122	123	124	125	Avg.
Date, 1916 (P.M.)	9-11	9-11	9-11	9-11	9-11	9-11	9-11	9-11	.....
Opening number	13	13	13	13	13	13	13	13	.....
Height of water on mercury gage, in	66 6	67.2	66.6	66.2	66.2	66.6	66.3	66.3	.....
Height of mercury gage, in	12.1	12.7	12.1	11.7	11.4	12.1	11.5	11.4	.....
Correct height of mercury gage, in	7.20	7.76	7.20	6.83	6.53	7.20	6.63	6.53	6.99
Temp. leaving condenser, T_1, deg. fahr	73	76	77	77	78	76	73	73	75.4
Temp. entering condenser, T_2, deg. fahr	67	70	69	71	71	68	69	68	69.1
Cooling range, $T_1 - T_2$, deg. fahr.	6	6	8	6	7	8	4	5	6.3
Air temp., T_a, deg. fahr	72	73	72	74	74	69	74	74	72.8
$T_2 - T_a$	−5.0	−3.0	−3.0	−3.0	−3.0	−1.0	−5.0	−6.0	−3.7
Dry-bulb temp., deg. fahr	74	75	76	75	75	72	74	75	.....
Wet-bulb temp., T_w, deg. fahr.	64	64	66	68	66	62	66	66	.....
Wind velocity, ft. per min	157	244	138	144	238	191	177	129	177
Wattmeter reading, kw	4.50	4.90	4.45	4.35	4.30	4.35	4.10	4.10	4.38
Vacuum, in. mercury	28.50	28.25	28.25	28.25	28.25	28.00	28.00	28.00	28.19
$T_1 - T_w$	9	12	11	9	12	14	7	7	10.1
$T_2 - T_w$	3	6	3	3	5	6	3	2	3.9
Efficiency $= \frac{T_1 - T_2}{T_1 - T_w} = E$	0.667	0.500	0.727	0.667	0.583	0.571	0.571	0.714	0.624
Weather	Partly cloudy								

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TABLE 5 TESTS OF THOMAS SPRAY HEAD WITH CONICAL SCREEN
(READINGS TAKEN EVERY 15 MIN.)

Test Number	142	143	144	145	146	147	148	149	Avg.
Date, 1916 (A.M.)	9-13	9-13	9-13	9-13	9-13	9-13	9-13	9-13	.....
Opening number	14	14	14	14	14	14	14	14	.....
Height of water on mercury gage, in	65.0	65.5	65.5	65.5	65.6	65.8	65.8	65.9	.....
Height of mercury gage, in	10.7	11.0	11.0	11.0	11.2	11.3	11.3	11.4	.....
Correct height of mercury gage, in	5.92	6.19	6.19	6.19	6.38	6.46	6.46	6.56	6.29
Temp. leaving condenser, T_1, deg. fahr	77	77	78	80	82	84	84	86	81.0
Temp. entering condenser, T_2, deg. fahr	69	69	70	70	72	72	73	75	71.3
Cooling range, $T_1 - T_2$, deg. fahr.	8	8	8	10	10	12	11	11	9.7
Air temp., T_a, deg. fahr	71	72	73	73	75	75	76	78	74.1
$T_2 - T_a$	−2.0	−3.0	−3.0	−3.0	−3.0	−3.0	−3.0	−3.0	−2.8
Dry-bulb temp., deg. fahr	71	72	73	73	74	75	76	78	.....
Wet-bulb temp., T_w, deg. fahr.	66	66	68	66	67	67	67	69	.....
Wind velocity, ft. per min	178	96	208	123	240	282	243	117	186
Wattmeter reading, kw	2.75	2.83	2.80	2.83	2.85	2.85	2.85	2.88	2.83
Vacuum, in. mercury	27.00	27.00	27.00	26.75	26.50	28.00	27.75	27.50	27.19
$T_1 - T_w$	11	11	10	14	15	17	17	16	13.9
$T_2 - T_w$	3	3	2	4	5	5	6	6	4.3
Efficiency $= \frac{T_1 - T_2}{T_1 - T_w} = E$	0.727	0.727	0.800	0.714	0.667	0.706	0.647	0.687	0.697
Weather	Fair								

TABLE 6 TESTS OF THOMAS SPRAY HEAD WITHOUT CONICAL SCREEN
(READINGS TAKEN EVERY 15 MIN.)

Test Number	150	151	152	153	154	155	156	157	Avg.
Date, 1916 (P.M.)	9-13	9-13	9-13	9-13	9-13	9-13	9-13	9-13	.....
Opening number	14	14	14	14	14	14	14	14	.....
Height of water on mercury gage, in	65.4	66.1	66.4	66.4	66.4	66.5	66.5	66.4	.....
Height of mercury gage, in	11.2	11.3	11.4	11.4	11.4	11.4	11.4	11.2	.....
Correct height of mercury gage, in	6.39	6.44	6.52	6.52	6.52	6.51	6.51	6.32	6.47
Temp. leaving condenser, T_1, deg. fahr	92	92	93	93	93	94	93	94	93.0
Temp. entering condenser, T_2, deg. fahr	81	81	82	81	82	82	82	81	81.5
Cooling range, $T_1 - T_2$, deg. fahr.	11	11	11	12	11	12	11	13	11.5
Air temp., T_a, deg. fahr	81	80	81	82	81	81	79	79	80.5
$T_2 - T_a$	0.0	1.0	1.0	−1.0	1.0	1.0	3.0	2.0	1.0
Dry-bulb temp., deg. fahr	79	79	80	80	79	79	78	78	.....
Wet-bulb temp., T_w, deg. fahr.	70	70	70	70	71	71	71	71	.....
Wind velocity, ft. per min	97	79	180	365	164	240	78	60	158
Wattmeter reading, kw	2.75	2.75	2.80	2.80	2.75	2.80	2.75	2.75	2.77
Vacuum, in. mercury	26.50	26.50	26.25	26.25	27.25	27.25	27.50	27.25	26.84
$T_1 - T_w$	22	22	23	23	22	23	22	23	22.5
$T_2 - T_w$	11	11	12	11	11	11	11	10	11.0
Efficiency $= \frac{T_1 - T_2}{T_1 - T_w} = E$	0.500	0.500	0.478	0.521	0.500	0.521	0.500	0.565	0.512
Weather	Fair					Partly cloudy			

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TABLE 7 TESTS OF THOMAS SPRAY HEAD WITH AND WITHOUT SCREEN

	With screen	Without screen	With screen	Without screen	With screen	Without screen	With screen	With screen	Without screen	With screen	Without screen	With screen	Without screen	With screen	Without screen
Test Number	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109
Date, 1916	7-20	7-20	7-20	7-20	7-20	7-20	7-20	7-21	7-21	7-21	7-21	7-21	7-21	7-21	7-21
Opening number	13	13	13	13	13	13	13	11	11	12	12	13	13	13	13
Height of water on mercury gage, in	64.9	64.3	65.3	64.7	67.3	64.1	65.2	69.7	63.3	65.0	65.3	79.4	79.3	79.5	79.5
Height of mercury gage, in	10.2	9.9	10.8	9.7	12.8	9.3	10.5	15.0	8.7	10.5	10.5	21.4	21.3	21.2	21.3
Correct height of mercury gage, in	5.43	5.17	6.00	4.94	7.85	4.59	5.71	9.88	4.05	5.72	5.70	15.56	15.57	15.36	15.46
Gallons per minute	63.3	62.5	64.5	61.8	67.5	62.5	69.0	32	.....	65	64	94	94	94	94
Temp. leaving condenser, T_1, deg. fahr	105	105	105	98	98	98	98	93	98	99	99	95	94	95	95
Temp. entering condenser, T_2, deg. fahr	87	89.5	90	88.5	88	86	84	83	86	87	85.5	83	83	83	83
Cooling range, $T_1 - T_2$, deg. fahr	18	15.5	15	9.5	10	12	14	10	12	12	13.5	12	11	11	12
Air temperature, T_a, deg. fahr	84	85	85	85	85	84.5	85	86	86	86	86	87	89	89	89
$T_2 - T_a$	3.0	4.5	5.0	3.5	3.0	1.5	−1.0	−3.0	0	1.0	−0.5	−4.0	−6.0	−6.0	−6.0
Dry-bulb temperature, deg. fahr	82	86	85.5	86	86	84.5	85.5	86	86	86	86	88	88	89	88.5
Wet-bulb temperature, T_w, deg. fahr	76	78.5	76	79	77.5	74.5	75.5	78	79	78.5	77	79	79	78.5	77
Relative humidity, per cent	76	71	68	73	68	62.5	63	70	73.2	71.5	66.5	66.8	66.5	62	59
Wind velocity, ft. per min	214	161	254	190	222	225	245	173	192	129	101	157	171	265	205
Wattmeter reading, total kw	1.58	1.58	1.62	1.53	1.62	1.57	1.68	3.00	2.75	2.75	2.68	2.25	2.25	2.25	2.23
Net kw	1.20	1.21	1.22	1.16	1.20	1.20	1.24	2.55	.....	1.99	1.93	0.75	0.75	0.75	0.73
Net watts for cooling 1 gal. 1 deg. fahr. (P)	1.054	1.25	1.26	1.978	1.779	1.600	1.283	8.0(?)	.....	2.55	2.23	0.665	0.725	0.665	0.66
Net watts per deg. cooling	66.6	78.1	81.3	122.2	120	100	88.5	255	.....	166	143	62.5	68	62.5	62
$T_1 - T_w$	29.0	26.5	29.0	19.0	20.5	23.5	22.5	15.0	18.0	20.5	22.0	16.0	15.0	16.5	18.0
$T_2 - T_w$	11.0	11.0	14.0	9.5	10.5	11.5	8.5	5.0	7.0	8.5	8.5	4.0	4.0	4.5	6.0
Efficiency on wet bulb $= \frac{T_1 - T_2}{T_1 - T_w} = E$	0.621	0.585	0.518	0.500	0.488	0.511	0.622	0.667	0.667	0.585	0.614	0.750	0.733	0.727	0.667
Weather	Fair, pond in sun							Partly cloudy				Sun			

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TABLE 8 TESTS OF TYPES OF NOZZLES WITH SPIRAL CORES

(No Screen Used. High Pressure Necessary. Small Capacity)

Type of Nozzle	3-in. Star			2-in. Star		Two 1-in. Sprays							
Test number	11	12	13	14	15	16	17	18	86	87	88	89	90	91
Gallons per minute	53.7	67.7	79.7	25.8	34.4	23.7	23.7	21.5	31	31	31	37	34	30
Pressure, in. mercury	10.76	15.72	20.89	11.70	20.88	15.52	15.04	11.47	12.83	12.83	12.12	19.86	14.01	10.16
Initial temperature, T_1, deg. fahr.	108.3	98	98	113.5	104.8	125	105.5	101.5	114	100	94	120	105	98
Final temperature, T_2, deg. fahr.	86.7	81	80.4	80	77.3	74	71.5	73	84.5	86	86	82.5	88	89
Cooling range, $T_1 - T_2$, deg. fahr.	21.6	17	17.6	33.5	27.5	51	34	28.5	29.5	14	8	37.5	1	9
Dry-bulb temperature, deg. fahr.	83.4	76	72.2	71	72.7	66	63.3	70	87	86.5	85.5	86	89	90
Wet-bulb temperature, T_w, deg. fahr.	69.6	60	61.2	57.7	57.3	54	52.7	57	77	76	75.5	77.5	78.5	79.5
Humidity, per cent	48.6	38	52.8	43.4	37.4	44.4	48.4	43.6	63.4	61.6	62.8	68.4	62.6	62.8
Wind velocity, ft. per min.	372	270	162	268	395	264	229	332	215	241	107	195	236	59
$T_2 - T_w$	3.3	5.0	8.2	9.0	4.6	8.0	8.2	3.0	−2.5	−0.5	+0.5	−3.5	−1.0	+1.0
Total kw	1.573	2.00	2.58	1.45	2.02	1.66	1.57	1.38	1.80	1.82	1.75	2.15	1.78	1.48
Net kw	1.273	1.59	2.04	1.37	1.871	1.60	1.51	1.33	1.68	1.70	1.63	1.08	1.63	1.37
Net watts per gal. per deg. fahr.	1.099	1.382	1.455	1.585	1.98	1.322	1.874	2.170	1.838	3.91	6.58	7.79	2.82	5.08
Net watts per deg. cooling	54.2	93.6	116.0	40.9	68.1	31.3	44.4	46.7	57.0	121.3	203.9	78.8	96.8	152.2
$T_1 - T_w$	38.7	38.0	36.8	55.8	47.5	71.0	52.8	44.5	37.0	24.0	18.5	42.5	26.5	18.5
$T_2 - T_w$	17.1	21.0	19.2	22.3	20.0	20.0	18.8	16.0	7.5	10.0	10.5	5.0	9.5	9.5
Efficiency $= \frac{T_1 - T_2}{T_1 - T_w} = E$	0.558	0.447	0.481	0.600	0.404	0.718	0.643	0.641	0.796	0.584	0.432	0.883	0.642	0.486
Weather									Pond in sun, weather fair					

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DISCUSSION

PAUL A. BANCEL (written). The curves of cooling efficiency in the paper are of great use in predetermining the size of pond for a given duty. It is questionable, however, if the expression connecting efficiency and temperatures, namely, $E = (T_1 - T_2)/(T_1 - T_w)$, is applicable outside of certain narrow limits of wet-bulb temperatures T_w. Some readings taken recently on a Thomas nozzle in cold weather were as follows:

Temperature of hot water, deg. fahr	115	91
Temperature of cold water, deg. fahr	85	68
Temperature of air, deg. fahr	31	26
Pressure at nozzle, inches of mercury	8	10
Efficiency, per cent	36	35
Character of spray	Fine	Fine

In calculating the efficiency the wet-bulb temperature was assumed equal to the dry-bulb, and therefore the figures for efficiency are slightly high. For the same conditions the chart of Fig. 9 indicates efficiencies from 55 to 65 per cent. In other words, if this chart were used to predict cooling for winter conditions, temperatures of sprayed water would be indicated much lower than those actually obtainable.

This phenomenon can be explained by the fact that cooling by evaporation goes on less readily in cold weather than in warm. Thus, suppose the air rising through the spray is heated 25 deg. fahr. Then the volume of air required to take up 1 lb. of moisture or "absorb" about 1000 B.t.u. will be as follows:

Air required, cu. ft	2500	1800	1300	1000	750	600	500
Wet-bulb temp., deg. fahr	30	40	50	60	70	80	90

In warm weather only one-third to one-fifth as much air is needed to take up the same heat.

This decrease in relative efficiency of cooling was noted some time ago in the analysis of cooling-tower performances. For this purpose a coefficient of heat dissipation was used, equal to the heat units per hour per degree difference of temperature between mean water temperature and wet-bulb temperature per square foot of air-flow area. For two types of towers the following values were found:

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Wet-bulb temperature, deg. fahr.	Coefficient of Heat Dissipation	
	Forced-draft tower	Chimney-draft tower
−10	500	.....
+30	700	.....
50	1000	.....
60	1250	340
70	1500	.....
80	1800	440

In applying empirical formulæ for spray cooling the influence of the season of the year should not be overlooked. The same caution applies when making acceptance tests of cooling ponds or towers.

A MEMBER called attention to Par. 14, where a water loss of 0.31 per cent per hour was mentioned, this apparently referring to Fig.13, in which the cooling range was from 178 deg. down to 125 deg. Theoretically, the loss by evaporation for 10 deg. cooling would be 1 per cent, and he thought it should be explained how, in the case of Par. 14, the loss was but 0.31 per cent with a cooling range of 53 deg.

B. R. T. COLLINS (written). Referring to Fig. 12, which gives efficiencies with water falling on the bare cement bottom of pond as compared with those when the pond contains its normal amount of water, I note that the author's curves show 10 to 15 per cent higher efficiency with a full pond, thus controverting his statement in regard to the advisability of constructing a pond with practically no water in it. I believe the result shown by the curves indicates that a bare pond absorbs heat from the surroundings more readily and conducts this heat to the water sprayed upon it, thus raising the temperature of the water and reducing the efficiency. Hence a certain depth of water should be carried in the pond to prevent this, 2 or 3 ft. being the best depth when everything is taken into consideration.

In Par. 14 the author states that the loss from cooling ponds with non-adjustable nozzles, in windy weather, is as high as 10 or 15 per cent. The experience of our company is summed up by a typical case of a test made on a pond with non-adjustable nozzles at Hutchinson, West Virginia. An accurate record of all make-up water delivered to the pond during the month of August was kept, and this showed a total loss due to evaporation, drift and leakage, of 1.33

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per cent of the water sprayed. The capacity of this pond was 3000 gal. per min.

There is one disadvantage in using adjustable nozzles such as the author describes when installed over a natural pond. The water in these ponds generally contains a certain amount of vegetable growth. This tends to clog the spiral slot, resulting in reducing the capacity of the nozzle appreciably, and increasing the size of the drops to a very considerable extent. This occurs in the course of a short period of time, about 10 to 15 min. after starting with a clean nozzle. This of course is an inherent difficulty with all nozzles of this type. It is fair to assume that an artificial pond or basin would become foul in the course of time and cause the same difficulty.

The results reported in the paper bear out our experience in that the highest efficiency of a spray-cooling system is obtained in hot, humid weather, and the lowest efficiency in cool, dry weather. This is an advantage which a spray system has over cooling towers, as our experience has shown that hot, humid weather reduces the efficiency of towers to a very considerable extent. This, it is believed, is due to the fact that the air is in contact with the water a much shorter length of time with a spray system than it is with a cooling tower of standard manufacture.

EDWIN BURHORN (written). The title of the paper is somewhat misleading as it is entirely too broad, the subject-matter being devoted to cooling water by means of spray nozzles, particularly to a form of spray nozzle devised by the author.

Spray nozzles are used for cooling water for power-plant purposes but can also be used for cooling water for any purpose. Furthermore, there are many other methods of cooling water than those mentioned by the author and these different methods should have been covered by the author in order to fully justify the selection of the broad title of the paper.

The paper is interesting as far as it goes, but is not conclusive and leaves much to be desired. It is in line, however, with most of the papers that have been submitted from time to time covering various methods of cooling water, these limiting themselves to a particular apparatus. Attempts have been made to devise some general formula that could be used in connection with cooling towers, but on account of the many variables in connection with such work, the subject was given up. The process of cooling water is of such consequence and so vitally affects the efficiency of many operations

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that it is highly desirable that some reliable investigation be made regarding the relative values of the different methods available.

Among these methods are the plain cooling pond, spray nozzles alone or in connection with cooling ponds, cooling towers operated by means of air forced in by fans, or cooling towers in which the air is exhausted, cooling towers operating under the action of natural draft created by a stack, and cooling towers of the so-called "atmospheric" type, which operate through the action of natural air currents.

It should be borne in mind that all cooling systems are dependent on atmospheric conditions and vary with varying atmospheric conditions, and the maximum point of cooling is that of the temperature of the wet-bulb thermometer and not the temperature of the dew-point. If the cooling system were so designed, with proper cooling surface, etc., it could reach the temperature of the wet bulb under all atmospheric conditions. From a practical standpoint, however, it is not advisable to so design such apparatus, as the great cost would not be justified by the additional reduction in temperature.

A comparison of the various cooling systems should include not only the cooling apparatus itself but also the auxiliary apparatus such as pumps for pumping the water and fans, if any, for creating an artificial circulation of air. In other words, the cost of operating various systems per annum should be investigated so that reliable data could be obtained. The interest on the investment and depreciation should also be taken into consideration and an investigation of this character would undoubtedly be of exceedingly great value. It would involve, however, considerable labor and expense.

Referring to the paper, it will be noted that the curves in Figs. 7 and 8, showing the variation of efficiency of the adjustable spray head, were obtained by adjusting the spray head to suit the weather conditions existing at the time. It would be interesting to know how such adjustment is made and on what basis, as the weather conditions change from day to day and vary abruptly even in a single day. It seems somewhat impractical to adjust these nozzles to suit all weather conditions. In a large installation, also, it would seem impossible to make this adjustment without shutting down the water supply or constructing a series of tunnels underneath the collecting basin to give accessibility to the adjusting rods. It is also somewhat difficult to tell whether the nozzle is adjusted for the most efficient conditions without carrying on a continuous series of tests unless the object were to attain a temperature of the wet-bulb ther-

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mometer, and of course in that case the nozzle would be adjusted until that temperature was obtained. The results of tests, however, seem to indicate that the reduction of temperature is, under most conditions, over 10 deg. above the temperature of the wet-bulb thermometer.

The curves in Fig. 10 are intended to show the wide variation of efficiency when proper adjustment of spray head is neglected. It is therefore of considerable interest to know how the spray heads can be kept properly adjusted to suit the ever-changing atmospheric conditions. The black circles refer to non-adjustable nozzles and the other circles to adjustable nozzles operating "without any attempt to obtain high efficiency." There does not seem to be much choice between the two types of nozzles and it would have been interesting to have seen the results for a period of one year where the adjustable nozzles had been operated with an attempt to obtain high efficiency.

In reference to Fig. 12, in which the efficiency is lower with a bare pond than with a full pond, Professor Thomas seems to be surprised at the results. This should not be at all surprising, as it is what would naturally be expected. The full pond offers considerable evaporating surface in addition to the surface exposed by the spray, and, furthermore, the evaporating surface is near the ground level where it can take advantage of prevailing air currents. On the other hand, the bare pond most likely did not offer the same amount of cooling surface as the full pond, and, furthermore, what cooling surface there was, was quite some distance below the ground level. This would therefore make it less accessible to air currents and naturally there would be less evaporation with the bare pond. The same reasoning may explain why the spraying on superposed inclined cement plates showed a falling off of efficiency owing to the fact that the cement plates may have offered obstruction to the prevailing wind currents and also reduced the cooling surface by collecting the spray into larger drops. No details showing the inclined cement plates were given and therefore a definite conclusion on this point cannot be reached.

The effect of wind velocity on cooling range is indicated in Fig. 14, but not very much is said on this subject. This, however, is a very important matter in obtaining satisfactory results. As the cooling of the water is done partly by convection and partly by evaporation, it is absolutely necessary in order that this process may continue that the air be in motion. Where the humidity is 100 per

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cent, all cooling is practically by convection, and the amount of cooling is limited entirely by the amount of air that passes over the water to be cooled. It can be readily seen, therefore, that under certain conditions a higher wind velocity will give very much better results. It is seldom, however, that the air is absolutely quiescent, there being at all times some wind movement; but even where there is no wind movement, the action of the heated water on the air would tend to create upward air currents and thus facilitate the action of the cooling. Were this not so, there would be absolutely no cooling possible unless there were wind movement. The efficiency of the cooling apparatus is based not alone on the range of cooling but also on the loss of water from all causes. Professor Thomas reports on the loss "due to evaporation." There is, however, an additional loss due to windage and this must be carefully known, as the total loss is what must be made up, and, if purchased, will represent an item of expense that should be taken into consideration. The loss from windage will depend on the velocity of the wind and also the size of the pond, and the size of the pond should be dependent on the maximum pressure of discharge at the nozzle.

The Johns Hopkins pond has an area of 962 sq. ft. and the amount of water handled varied from 20 gal. to 300 gal. per min., as indicated in Fig. 8. In the first case the area was about 48 sq. ft. per gal. per min., whereas in the second case the area was about 3.2 sq. ft. per gal. The loss of water due to windage would of course vary considerably, particularly with the average wind, but apparently no data are given on this important subject.

The loss due to evaporation would depend on atmospheric conditions, and where all the cooling is done by evaporation the loss would be about 1 per cent every 10 deg. the water is cooled. It should be noted that Professor Thomas states the loss from non-adjustable nozzles in windy weather is as high as 10 to 15 per cent, but he does not show how with an adjustable nozzle the loss can be reduced by merely adjusting the nozzle. The windage loss might be greater with an adjusting nozzle owing to the fine spray, whereas the loss due to evaporation should be the same regardless of the nozzle, provided the cooling results are the same.

There seems to be some mistake in regard to the loss due to evaporation at the pond at Sparrows Point, Md., given by Professor Thomas as 0.31 per cent. At this pond, apparently, the water was reduced in temperature from 178 deg. fahr., to 125 deg. fahr., or a reduction of 53 deg. Unless the test was made in winter when

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there was no evaporation, or very little, then, undoubtedly, the loss should have been much higher; and particularly in the summer when the air temperature is high, the greater part of the cooling will be done by evaporation, and in this case, if all the cooling were done by evaporation, the loss would have been, theoretically, 5.3 per cent.

Professor Thomas also endeavors to prove the advantage of the adjustable spray nozzle over the ordinary type of spray nozzle and states that the adjustable nozzle permits "regulation of the spray to suit weather conditions and to minimize loss of water and inconvenience to the nearby buildings due to driftage in windy weather." This is an admission of the inefficiency of the spray nozzle in general and a claim for an improvement due to the adjustable type of nozzle, but no proof is offered to justify the conclusion.

The curves in Fig. 8 show a variation of efficiency of the adjustable spray head with variation of capacity, but a close examination of the three curves shows them to be very nearly identical, the variation being only slight and hardly any advantage on this account.

Professor Thomas also states that "it has been somewhat surprising to find that very good cooling effect frequently obtains in very humid and even in rainy weather." He does not refer to any particular tests that have caused the surprise, but bearing in mind that it is possible to cool water to the temperature of the wet-bulb thermometer, nothing would be surprising unless the temperature were reduced below that of the wet-bulb thermometer.

The results of cooling with spray nozzles were also compared with a few selected tests of one type of cooling tower, but as this cooling tower was not necessarily the most efficient obtainable, the comparison is not a fair one. The details of construction of the cooling towers were not given and the amount of water circulated in the cooling tower at the time the tests were made may not have been the full capacity of the tower. The data given were not sufficient to make these tests of any value for comparison. If, however, the cooling towers were all operated under their figured capacity, they show a variation *in efficiency* that seems to indicate improper design in some cases.

In Table 2, test No. 4 shows an efficiency of 0.928, whereas test No. 5 shows an efficiency of 0.391. If Professor Thomas would compare the results of his spray nozzles with the results that have been obtained with atmospheric-type cooling towers, in which the water has been reduced to within 1 to 5 deg. of the temperature of the

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wet-bulb thermometer, varying with the atmospheric conditions, he would then find that his results do not compare very favorably with those of that type of cooling tower.

Attention is also called to Table 8, showing tests of nozzles with spiral cores, and it is noted that on the test of nozzles consisting of two 1-in. sprays high efficiencies are shown, namely, 0.798 in one case and 0.883 in the other. Table 7, of tests of the Thomas spray

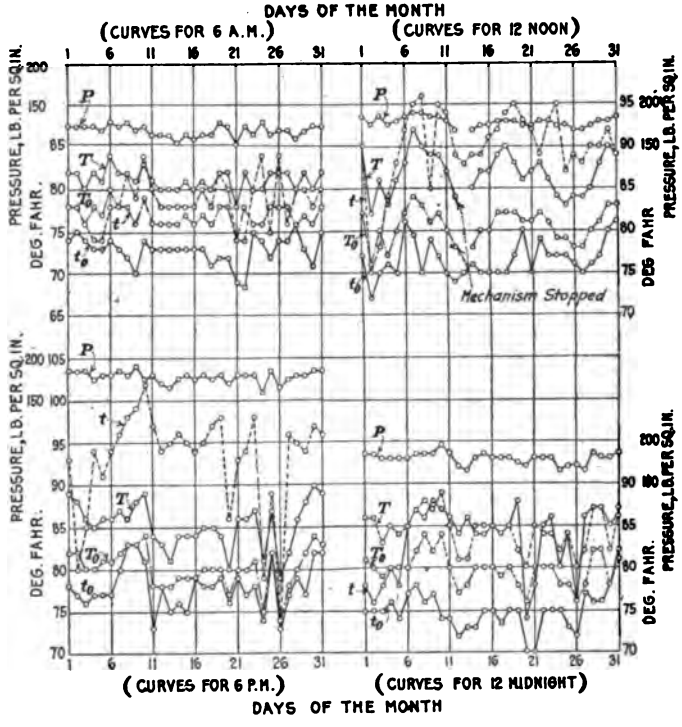

FIG. 20 CURVES SHOWING HIGH EFFICIENCIES WITH ATMOSPHERIC TOWERS

head with and without screen, does not show any test where the efficiency equals these, the highest shown being 0.75, in test No. 106, using the Thomas head with wire screen.

The spray-nozzle system undoubtedly has a field of usefulness but it is not adapted for cooling water where high efficiency is necessary or advantageous, such as in refrigerating and ice-making apparatus and steam turbines. In these plants the lower the temperature of the water used for cooling, the higher the efficiency of the

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apparatus, and cooling towers of the atmospheric type are able to cool the water to within 5 deg. of the temperature of the wet-bulb thermometer, whereas with the spray nozzles it is shown to be practically impossible to reach closer than 10 to 15 deg. of the wet-bulb temperature. In certain uses where high efficiency is not necessary, or for temporary service only, the spray nozzle is well adapted.

In order to show the high efficiencies actually obtained in practice with towers of the atmospheric type, the chart shown in Fig. 20 is submitted. This chart shows by curves the daily temperatures during the month of July, the readings being taken each day of the month at 6 a.m., noon, 6 p.m. and midnight. These tests were taken from a tower in regular operation at Dallas, Texas.

Attention is called to the generally close shape of the curves of the temperature (T_0) of the water leaving the tower and the temperature (t_0) of the wet-bulb thermometer, and particularly it should be noted that in several cases the temperatures were identical and the maximum variation about 5 deg. The wind velocity, of course, varied, and it should be noted that very little advantage could have been obtained in any of these tests had the wind velocity been higher than it really was.

This fact proves merely that the tower was properly designed and of sufficient surface in order to cool the water within 5 deg. of the wet-bulb thermometer under practically the worst possible atmospheric conditions. Furthermore, under the best atmospheric conditions the water was reduced to the temperature of the wet-bulb thermometer.

A. G. CHRISTIE, who presented the paper in the absence of the author, said in reply to Mr. Collins that they had found the bare pond not so efficient as the pond with a considerable amount of water. On the other hand, a full pond was not desirable in the North. There was a mean in the depth of pond which gave general efficiency — in their own particular pond about 18 to 20 in. instead of 3 ft.

THE AUTHOR. The writer is much interested in the various discussions which have been contributed to this paper and which form a valuable addition to it.

Regarding the expression for efficiency used on the paper, namely, $E = (T_1 - T_2)/(T_1 - T_w)$, where T_w is the temperature of the wet bulb, this does not give a really satisfactory means of measuring

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efficiency. As shown by the results in the paper, and by some of the conditions described, the cooling is only partially due to evaporation and is largely due to conduction resulting from direct contact with the air.

Mr. Bancel has pointed out that the expression for efficiency gives values which are lower than those actually obtained in winter time. The writer hopes to find opportunity to work out an expression which will take account of the cooling by conduction as well as by evaporation.

It is noticed that Par. 13 has not been entirely clear to some of the speakers. The spraying on the bare cement bottom of the pond gave less cooling than was obtained by spraying into a pond containing water, as shown on Fig. 12. This is confirmed by the remarks of one or two speakers.

The remarks of "A Member" regarding percentage of evaporation were apparently made upon the assumption that all of the cooling effect was due to evaporation, while, as above noted, the writer has found this is not the case. Very good cooling frequently takes place during very humid weather, particularly if the air is in motion near the pond.

With regard to the adjustable feature referred to by Mr. Collins: The spray head described in the paper is quite easily kept free from even stringy vegetable growth, but in order to do this the operating gear should be worked at least once a day in cases where any considerable quantity of vegetable growth is carried by the water. Mr. Collins brings out in an interesting way the fact mentioned above concerning the high cooling effect often obtained during hot, humid weather. This further shows the necessity for a more complete expression for efficiency than that which the writer has used.

Attention should be called to the fact that the results given in the paper for the author's adjustable spray head have been obtained with low pressures at the spray head, these being in the neighborhood of 6 or 7 in. of mercury. An important consideration in this spray head is that the water is finely divided and well spread out into the atmosphere with very low pressures.

The most important element in cooling water under given conditions seems to be pressure at the spray head, or, in other words, fineness of subdivision of the water. There are at least seven variables to be taken into consideration and which should appear in a complete expression for efficiency, but the cooling effect appears to vary more consistently with pressure than with any other one thing. This

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is shown by curves in Figs. 7 and 11. The type of nozzle, however, has a good deal to do with the cooling effect obtained at the lower pressures. Some nozzles with a single vertical outlet have a tendency to "bunch" the water directly above the nozzle, particularly at low pressures, and this prevents intimate contact with the air. The author has aimed, in the design of his spray head, to spread the water out in thin layers of extensive area, and this is accomplished at low pressures as well as at high. At high pressures, say, above 12 or 15 in. of mercury, good efficiencies are obtained by any well-designed nozzles, but at the lower pressures this does not appear to be the case.

One of the speakers asks how the adjustable nozzle helps toward economizing loss due to windage. The answer is that during windy weather a good cooling effect can be obtained with less fine subdivision of the water than is required in still air. Consequently the adjustable nozzle can be opened up during windy weather so as to produce a coarser spray which blows away less readily. This results in satisfactory cooling effect, due to better contact with the air than is possible when the wind is not blowing. The practical advantages of this have been demonstrated quite conclusively during the writer's experience with the adjustable spray head.

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No. 1609

THE STEAM MOTOR IN THE AUTOMOTIVE FIELD

By E. T. Adams, Syracuse, N. Y.
Member of the Society

The tremendous increase in the demand for automotive power has outdistanced the ability of the gasoline engine to meet this demand, chiefly on account of the condition that the supply of fuel is not now equal to the requirements.

The steam unit has many advantages for automotive service. Its high torque at low speed, its overload capacity, its smooth, flexible speed and power control have remained the standards of excellence, reached for but never attained by any gasoline motor.

The design of the steam unit is simple and many features of construction have been introduced which tend toward long life and low cost of upkeep.

Numbers of new steam trucks, tractors and pleasure cars are in service, or in process of manufacture or design. This effect and this demand will have a profound influence on the automotive industry.

IN the general power field this is the era of steam. In the field of automotive power, even more absolutely, this is the era of gasoline.

2 The supremacy of steam for general power purposes has been attained only after years of competitive development. The gasoline motor has developed without serious competition and in a very short time. We therefore lack the assurance that its present preëminence in all departments of the automotive field may not be based on causes other than superior fitness for the service, such, for example, as a condition of the oil industry, now outworn, or upon the initial unreadiness of other types of motor.

3 At the present time the question as to the relative fitness of the gasoline as compared with the steam motor for automotive service is receiving most serious attention. New developments and new inventions in steam motors have revolutionized the status of steam at the very time when the oil industry has reached a position absolutely the reverse of that which led to, and fostered the growth

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of, the gasoline engine. Two interrelated economic developments are especially noteworthy. First is the tremendous increase in the demand for automotive power. The use of the automobile has become universal, the use of the truck is at the beginning of an era of expansion which may prove equally great, and the farm tractor marks the beginning of a demand greater than all the others. The farm is the greatest single user of power: few people realize how huge a portion of the earth's surface must annually be cut into slices, turned upside down and pulverized to form a seed bed, and the expenditure of power which this involves. The excellence of the gasoline motor has led to its adoption for this and for other service for which it is economically unfitted, and we are fast working toward a condition where gasoline alone is not produced in sufficient quantity to meet the demand.

4 Second is the fuel situation. When the automobile industry was young the oil industry was dependent on the use of oil for light, and gasoline was a by-product — cheap, abundant and of excellent quality. Today the oil industry is based on oil for power, and gasoline is its foremost product. The supply, even with lowered quality and new processes of manufacture, is not equal to the demand, and the price is too high for many commercial uses. There will be some gain due to the perfection of vaporizing types of carburetor which will permit further lowering of the quality of gasoline, and some gain due to increased attention to economy, but the growth of the use of power in this field will be greatly hampered unless there is an increase in the quantity of fuel available far greater than can be expected from this source alone. This means the use of oils other than gasoline, and of methods other than carburetion and burning in an internal-combustion engine.

5 The steam-driven motor is the type which most readily meets this condition, and its use will receive a further impetus because the demand for gasoline is a seasonal demand and a steam unit using unpurified kerosene or similar light distillates will use these by-products of gasoline manufacture during the season in which they are produced. These by-products are produced in great quantities, are relatively cheap, and furnish an ideal fuel for the small-power steam boiler.

6 The steam unit has many advantages for automotive service. Its high torque at low speed, its overload capacity, its smooth, flexible speed and power control have remained the standards of excellence, reached for but never attained by any gasoline motor.

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The connection from motor to axle is simple and direct, without clutch, reverse or change gears. Steam is available at full boiler pressure and for practically full stroke to give torque to lift a loaded rear axle slowly and gently from a rut. Ahead and reverse follow the movement of a single lever, and acceleration and hill-climbing capacity hitherto unknown are at the operator's command.

7 High steam pressures and temperatures have been the rule, but a light, compact motor construction and high economy are attainable with steam pressures between 400 and 500 lb. gage, and thereby we avoid the tendency to carbonize the lubricating oil which is found at higher temperatures. There has been much interesting speculation on the economies due to the use of higher steam pressures and the best division of a given total heat between superheat and the temperature due to evaporation. But in the small units here considered, practical considerations, such as have been outlined, will doubtless govern design.

8 The chief force which is bringing about the increased use of the steam motor is its superior fitness for automotive service, especially in the commercial field. First, in truck service the upkeep of the gasoline truck, even with expert service, is now beyond reason and is a serious handicap to the business. Overloading and incompetent handling are blamed for this condition, but, practically, overloading is not preventable, and starting from a bad position is an unavoidable hazard. Racing the motor, coupled with the sudden application of the clutch, is the only answer to these conditions which the gasoline motor affords. The result is destructive to both power plant and transmission. The steam motor meets this situation by using steam for practically the full stroke of the piston and at any pressure which the tractive power of the wheel will permit. The available mean effective pressure on the steam piston under these conditions is fully five times the maximum available with a gasoline motor, and the motor speed for the same torque may be correspondingly low. With the steam unit the load is picked up gently, exactly as a locomotive starts a train. This tends toward low cost of upkeep.

9 Another point in favor of the steam unit is the extreme simplicity of the transmission — one pair of bevels or spurs, or direct drive on the worm shaft, is all that is required for light and moderate power work, with one additional reduction for heavy work and tractor service. There is no clutch, no reverse gear, only a simple

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direct drive from motor to axle. This again tends toward low upkeep and long life.

10 In early construction the motor naturally followed locomotive or marine lines. Modern steam motors are preferably of the multiple-cylinder type, designed for quantity production, using the tool equipment and shop methods of the modern gasoline-motor manufacturer. They are carefully balanced, are light and simple and capable of as high speed as may be desired. The uniflow type is largely used because of its simplicity and its high economy when operated non-condensing. Because of the high steam pressure, the most economical mean effective pressure is about the same as full-load mean effective pressure of the gasoline motor, and for the same power the cylinder sizes are about the same in the two cases. With this construction piston and valve require but little lubrication, the amount of lubricating oil necessary being far less than that used by older types of steam or by modern types of gasoline motors. The pistons and rods follow automobile practice. Alloy steel and aluminum are freely used and ball-bearing construction is employed where possible. Crankshafts and pins are oiled by a forced-lubrication system, bearing areas are ample, and the labor cost for adjustment and repair is naturally extremely low.

11 Boiler design exhibits greater variety than any other portion of the steam unit. The cylindrical fire-tube type, both with and without a water leg, have their advocates. The ordinary flash type is in use but not so much in favor, due, among other things, to its especial tendency to carbonize any lubricating oil introduced with the fuel. Tube boilers with natural or forced circulation are popular and effective. A forced-circulation, contraflow-tube type seems especially commendable in that it may be forced to almost any degree and is therefore responsive, light, compact and economical. The stack temperatures are readily brought down to 50 deg. above feed temperatures; the superheat is under good control and danger of burning or injury to the tubes is negligible. One advantage of the tube type is its absolute safety from destructive explosions.

12 All these features exhibit a very great advance over older constructions. They are popular because of their economy and safety, and because all these improvements tend toward longer life and lower cost of upkeep.

13 The furnace is the most important feature of the modern unit. All precedent is swept aside. With a light power oil as the established fuel there is no excuse for following old practice and

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merely firing oil into a combustion space originally designed for coal, and in later designs this is not done. First are established proper conditions for burning the oil; second are established proper conditions for utilizing the heat thus generated, and these are then combined. In one installation this leads to a design with the furnace practically at the top of the boiler, with forced feed of oil and air; this has proved a most acceptable and desirable location.

14 Various methods of controlling the oil are in general service. In the oldest type the oil under pressure is converted into a highly superheated vapor, which discharges past an adjustable needle valve drawing with it an air supply, fed and controlled as in a Bunsen burner. After proper mixing the mixture is burned as it issues from fine perforations in the grate. A pilot light which keeps the oil supply superheated is a necessary part of the equipment. In spite of its high economy and its honorable record in service, this system is steadily being displaced in the more modern designs. Objection is made that under certain conditions the pilot light and the heated oil under pressure are highly dangerous, and the clogging of the control valve by carbon and tars formed by the cracking of the oil is objectionable and expensive.

15 The mechanical atomizer of the type used in larger furnaces with heavier oils does not appear in use, but would seem to be well suited to the service. New systems of this general class are being very extensively tried out. These systems are important because they consider not only the proper burning of the oil, but also the commercially more important item of control. Considered as a unit, the vital control of the motor must be at the furnace. There must be control in proportion to load, in proportion to steam pressure and to maximum steam temperature, and also control directly responsive to the demands of the public. In a pleasure car starting from cold there must be steam to enable the car to be driven away in one minute. The mechanism of control, to be commercially successful, must be no more burdensome than the movement of a lever or the throwing of a switch. In a truck or tractor the demands are somewhat more moderate; but in general the steam unit must be practically on a par in the matter of starting with the gasoline unit, and the fact that in this respect also steam is now on a par with gasoline is one reason for the present impetus toward steam.

16 Where both air and oil are metered in under forced draft and in a boiler so flexible as those here described, it appears that a

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simple and entirely satisfactory method of heat graduation is to "cut in and cut out;" that is, to stop the supply of both oil and air entirely where it is desired to limit pressure or temperature, and to cut in again at full power when the pressure or temperature falls, this action of course being entirely automatic. With the safety which a tube boiler provides, a satisfactory system of water supply is a feed pump operated by any means whose speed or time of operation is directly proportional to the load. This involves attention to the water level and occasional adjustment by the operator, but as there is no serious penalty for his failure, this seems an entirely satisfactory method — perhaps more satisfactory than a type more strictly automatic.

17 Next to the fuel situation and the desire for reduced cost of upkeep, this new system of control is the most important development affecting the renaissance of the steam motor in the automotive field.

18 The exhaust is condensed to atmospheric pressure in an ordinary type of automobile radiator. The type with wide surfaces and thin water spaces has proved most effective. In a pleasure car complete condensation is secured in a small radiator often without the use of a fan. The efficiency of the radiator is reduced by excessive oil in the feed, but otherwise there are no disagreeable effects. Under these conditions fresh water supply is only needed at rare intervals, which again is a feature that has served greatly to increase the demand for the steam motor.

19 It is characteristic of the internal-combustion motor that it gives its highest economy at its maximum load, with rapid reduction in economy as the load is decreased. The reverse is true of the steam unit. It results from this that under usual operating conditions the steam unit is operating at its maximum efficiency, whereas the gasoline unit is operating at only fair efficiency. These efficiencies tend to meet, and in the two cases in actual service the quantity of fuel per brake horsepower-hour should not be materially different.

20 The difference in cost between gasoline and power oil, when coupled with a reduced cost of lubricating oil, represents an appreciable reduction in fuel cost in favor of the steam unit and one of importance to the truck and tractor operator. In the case of the automobile, where a small horsepower represents great mileage, this item is of lesser importance; but it lends romance to engineering to note that the joy of driving the smooth, flexible steam motor is likely

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to cause its extensive adoption, first in the field which commercially needs it least.

21 In our interest in newer conditions and later developments we should not overlook the splendid record of the builders who have long been prominent in this field. It is this pioneer work which has demonstrated the advantages and emphasized the deficiencies of the steam unit and has formed the basis on which the engineer of today is building.

22 From the earlier experience with steam power we have learned the necessity of treating the various elements of a steam-power plant as parts of a single unit. From the internal-combustion motor we have learned the necessity for design on a production basis. From the oil industry we have learned what fuels are most readily available, considering both method of manufacture and distribution. And from the public we have clear-cut demands based on extended experience with both gasoline and steam in all classes of service. The designer of the steam unit, therefore, has before him unusually complete data relative to all phases of the problem.

23 On the part of the manufacturer and of the public there is evidence of tremendous interest. Numbers of new trucks, tractors and pleasure cars are in service, or in process of manufacture or design. This effort and this demand will have a profound influence on the automotive industry. Whether it shall result in the supremacy of steam over gasoline is of minor import. The important fact is that it will surely result in a tremendous broadening of the usefulness and influence of automotive powers.

DISCUSSION

JOHN YOUNGER (written). The paper is interesting and of value, inasmuch as it draws attention to the fact that the demands that are being made on gasoline as a source of power are probably beyond the power of the oil refiners to supply.

There has, however, been a marked trend in design to improve carburetors to a point where kerosene can be used, and this, of course, to a certain extent, if successful, will practically double the quantity of gasoline available. There are today many internal-combustion engines running reasonably satisfactorily on kerosene, and the next year or two should see tremendous strides in the use of this or even slightly heavier fuels.

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The point that the author raises in Par. 15 that control must be almost instantaneous, would surely limit the fuel required in the steam boiler to something which is more easily vaporized than a heavy crude oil, for example, and, as a matter of fact, most of the experimenters have found it necessary for this purpose to use at least kerosene.

The author's statement in Par. 8 that "the chief force which is bringing about the increased use of the steam motor is its superior fitness for automotive service, especially in the commercial field," is somewhat doubtful when the situation is studied at large. So far as the writer can see, there is no great demand, or any demand to speak of, for a steam automotive vehicle, for the simple reason that they were tried out as recently as ten years ago and practically abandoned. If one turns to the situation in England, where steam vehicles using coal, coke and gasoline have been used for some fifty years, it will be found that the gasoline truck and the kerosene truck have supplanted the steam vehicle almost entirely. The same condition is found in the agricultural-tractor industry at the present moment, where the steam vehicle, which has so long been used by the farmer, is being actually forced out by the internal-combustion engine.

The author's statement in Par. 8 that the upkeep of the gasoline truck, even with expert service, is a serious handicap to the business, is, to say the least, very much exaggerated. The cost of repairs on the gasoline motor truck is surprisingly low. Repairs lower than two cents per mile are very commonly met with.

The seeming simplification of the steam vehicle is so purely on the chassis. The engine, as Mr. Adams stated in Par. 10, is very similar to the gasoline engine. The rear axle, the front axle, the frames, the springs, the driver's seat, the radiator, or rather the condenser, are all duplicated in the gasoline-driven truck. This leaves practically the transmission and clutch, and this mechanical device, which usually gives absolutely no trouble, is replaced by a high-pressure steam boiler with its elaborate piping and connections and firing; so far this has not been worked out satisfactorily.

Before becoming too enthusiastic on the advantages of the steam motor in the automotive field, the whole history of the subject should be studied without any bias, and present-day installations of trucks of all kinds, not only in this country, but abroad, should also be studied very closely, and the repairs, etc., analyzed.

In Par. 23 the author takes the very broad standpoint that

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whether steam will actually supplant gasoline or not is of minor import. It is quite possible that there can be a field for the two types, side by side, and anything that will help conserve our fuel supply must be worth while.

FRANCIS H. BAKER[1] wrote that he could hardly agree with the author that the gasoline truck was not an efficient factor in the lines of business in which it was employed. The figures compiled by nearly every truck manufacturer showing its relation to horse-drawn vehicles would verify this.

In regard to the cost of operation, the fuel used by steam cars would increase in price as the demand increased. This was invariably the case. The increase of cost of gasoline was a notable example.

The recent developments in boiler design enabling one to get a working pressure of steam in a short space of time had allowed the steam car to forge ahead rapidly, and had done away with one of the chief disadvantages.

WM. CLINTON BROWN (written). Simplicity in design and high economy in the use of steam have made changes in the automotive field which are revolutionary. For example, in tractor service it becomes possible to produce a steam tractor having a total weight, including fuel, water and operator, of around 125 lb. per b.hp. This is a machine lighter and far more compact than the majority of gasoline tractors. Compared with the standard type of steam tractor of the same power it is only about one-fourth the weight and less than half the size. It is therefore available for plowing as well as threshing. Because of the high economy of the plower plant the steam is condensed and again used, eliminating the high cost of hauling water — a large item in the cost of operation of ordinary types of steam tractor.

In truck service more emphasis is laid on the inherent fitness of the steam motor for such work, one which approximates the flexible speed control and the tremendous momentary overload capacity of the horse. In the pleasure-car field the steam motor arouses interest because of itsease of control, rapid acceleration, and wide range of speed and power.

JOHN STURGESS (written). In addition to the advantages enumerated by the author, the paramount benefit of steam power con-

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trasted with internal-explosive engines is the stored energy contained in the highly heated water in the boiler. With the standard type of automobile boiler, having a considerable water content, the available mechanical energy from this heat storage amounts to 1,500,000 ft-lb. — enough to drive a luxurious car half a mile up a 5 per cent grade with the burner extinguished, or run it at a fair speed from two to three miles on a level road. Or it is available for a great sustained effort over a short distance, to extricate the car from holes, mud or sand. This energy, stored in advance, means instantaneous power and maximum response of the vehicle, especially at lowest speeds.

Some figures on fuel cost under both test and actual road conditions may be of interest. In recent very accurately conducted tests on the test floor, an evaporation of 13.7 lb. of water per lb. of fuel (kerosene) has been repeatedly obtained, and also a steam consumption of 16.6 lb. per b.hp. This is a remarkably good performance for so small and compact a power plant, and gives a fuel cost of 1.806 cents per hp-hr. On road tests recently conducted daily over a distance of 180 miles (Newton to Springfield and back, over the Massachusetts central divide), a car weighing with load 4650 lb. has aggregated 6500 miles at an average speed of 30 miles per hour, total elapsed time between objectives, on a consumption of $\frac{1}{11}$ gal. of kerosene per mile, or, at the present market price of 10 cents per gallon, at a cost of less than one cent a mile. Internal-explosive cars of the same weight and under similar conditions rarely excel 10 to 12 miles to the gallon, which at current prices is equivalent to 2¼ to 2½ cents per mile.

The author very appropriately refers to the extreme simplicity of the connection from motor to axle, but I think the simplicity of the entire power plant merits equal emphasis. When I state that the modern automobile type of steam engine and its transmission has but 15 moving parts, compared to some hundreds in the internal-explosive engine and its transmission, some conception of the relative simplicity will be obtained. The thermal cycle of the steam plant may involve more stages, but the processes are more stable.

In Par. 10 the author remarks that modern steam motors are of the multi-cylinder type. I have no knowledge of any steam car using or proposing more than two cylinders, for nothing would be gained thereby; two cylinders (double-acting) give almost perfectly uniform torque. He further states that the uniflow type is largely used, giving as the reason its simplicity and economy when operated

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non-condensing. I know of only one advocate of the uniflow engine for automobile use, and I do not believe any claim is made by that advocate that cars have really been placed on the market as yet. In practice it does not prove any simpler than, if as simple as, the contraflow, while in its application to automobile needs grave difficulties are encountered which do not occur in stationary practice.

I cannot agree with the author's summary of boiler practice in Par. 11. As yet the water-tube type has not proved its commercial success, never yet having been marketed. The flash type is practically abandoned, owing to its several difficulties, including that of temperature and pressure control. Furthermore, as it lacks power storage, the most important benefit of the steam plant is lost. On the other hand, there are some thousands of cylindrical .fire-tube boilers in daily use under every kind of service, in many cases the boilers being eight to ten years old. Owing to the construction methods there has not been, to my knowledge, one single case of destructive explosion.

I must more emphatically disagree with — to the point of contesting — the author's statement in Par. 14 that "in spite of its high economy and honorable record in service, this system [namely, the conversion of oil under pressure into a vapor, and burning with a Bunsen type of burner, with pilot light for starting] is steadily being displaced by more modern designs." This implies that there is a different practice already in vogue. I doubt if there is any such practice. I doubt if a single car with such practice has ever been sold — certainly not within the last 15 years. Recent proposals have been made, but these are scarcely more than proposals, and hardly to be dignified by the title "modern designs." Further, as regards the possible element of danger from the pilot light in conjunction with heated oil under pressure, which the author refers to as having been the cause of objection, experience has demonstrated far fewer accidents from this source than with other forms of combustion, notwithstanding the many more cars equipped on the former system.

In regard to the question of starting, which must be accomplished from cold, according to the author in one minute to be commercially successful, the true perspective of starting facility should be made on the basis of several day's runs, — not the initial morning start, or on the still rarer occasions (not amounting to 1 per cent of all starts made) when steaming up from cold. It has been very truly advanced that if the gas-car owner could, by according a few more

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minutes to his initial morning start, provide stored power and obviate for all the rest of the day all manipulation of his self-starter, and all gear shifting and clutch pedaling, and dismiss from his mind all anxiety arising from differences between engine speed and car speed, he would most gladly strike the bargain. That is the case for the steam car, with the additional proviso that even the morning start can be effected in a few seconds by leaving the pilot light burning all night.

ALLEN C. STALEY (written). The author has ably brought out the peculiar fitness of steam power to the many needs of the automotive industry, but has left the inference that the older types have failed, and that rejuvenation is due to recent developments due to modern design.

From intimate experience with one of the best known of the so-called modern systems of combustion and also with the vaporizer type of burner, which the author characterizes as the oldest, I believe that I am qualified to say that while the atomized or liquid-fuel type of fire may possess excellent future possibilities, it is not yet beyond the promising experimental stage; and for automotive work the years of experience behind the older type make it more satisfactory and reliable at the present time.

As to the time required for raising steam, it should be borne in mind that the pilot light operates for days without attention and sufficient steam pressure can be always available for starting, not in one minute, but instantaneously at any time. The cost of operation or danger from such a pilot is insignificant, and it is much better for boiler, combustion chamber, and adjacent parts not to be subjected to the severe abuse of frequent sudden heating from cold.

As to engine design, the author seems to favor the uniflow as the logical type of highest development. I cannot agree with this for the following reasons:

First, owing to the early exhaust closure, an economical non-condensing uniflow engine has a high compression. With the low steam-chest pressures and variable cut-off demanded in automobile operation, valve lifting will occur. This type is more suitable for condensing operation with a vacuum.

Second, in order to relieve the compression, two expedients may be used — larger clearance space or excessive lead. The first causes loss in economy, thereby defeating the entire purpose of this design.

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The second causes a balky engine, or one that will tend to run backward at inopportune moments, as when starting from a standstill.

Third, a larger engine is required to get the same work, owing to the lower m.e.p. in a uniflow as compared with a contraflow design. This means extra weight and cost.

Fourth, the contention that having but one valve to control simplifies gear design and permits earlier cut-offs without diagram distortion, is neutralized by the fact that too early cut-offs produce a rough-running engine.

Fifth, the use of superheated steam in a contraflow non-condensing engine gives economy as good or better than is obtained with the uniflow, as has been amply demonstrated by test.

Sixth, over the normal loads due to car operation, a properly designed contraflow engine of suitable size for all conditions of operation will show as good mileage per unit of fuel as an equally suitable uniflow engine.

Turning now to steam generators, the fire-tube boiler stands alone for several reasons:

First, it has sufficient thermal storage capacity to meet reasonable or even unreasonable sudden demands for steam in excess of the normal requirements.

Second, the past and present designs of water-tube boilers have, in almost every case, been deficient in this respect, this being particularly emphasized by the semi-flash type of generator, which was quite popular at one time, but which required considerable jockeying before an excess of power could be secured.

Third, the semi-flash type also requires control of fuel and water from both temperature and pressure of the steam, introducing additional complications and sources of possible trouble. The fire-tube type with a definite water level needs merely a simple and rugged water-level regulator, a design that has seen service and given satisfaction on thousands of automobiles and in stationary plants.

Fourth, the ability to get up steam more quickly is claimed for the water-tube boiler. This obviously involves either sacrifice of power-storage capacity or the use of excessive combustion rates. In the former case overload ability is sacrificed, in the latter, economy.

Fifth, the water-tube boiler must have a suitable casing with refractory and heat-insulating lining to contain the boiler and hot gases. Linings are always a source of trouble and expense in stationary work, and there is no reason to expect the moving vehicle to give any less

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trouble in this respect. In contradistinction to this, the fire-tube unit is self-contained, requires no jacket, and has a natural circulation, a very desirable combination of conditions. Ample steam space is provided without recourse to separate steam drums, and there is much less danger from priming than with the water-tube type; as the latter type, unless it has separate steam drums, which is not usually the case, is without sufficient steam-liberating space.

Sixth, in the flash or semi-flash type of boiler, water must be furnished in proportion to the demand for steam, with resulting complication of control. In one of the most recent proposals a boiler with no free circulation and of the semi-flash type with flow in parallel instead of in series, is controlled by means of a water-level regulator only. This control is obviously insufficient, as all boilers of this type should have in addition a temperature control, as circulation and water level are of necessity indeterminate. The operation of a boiler of this type in parallel is also open to serious question, for as soon as this is attempted, it is impossible to control the flow of water, and overheating and burning of tubes will result.

J. D. NIES[1] submitted a written discussion in which he compared the steam automobile motor with the gasoline motor in smoothness of running, flexibility, reserve power, hill-climbing ability, acceleration, gear shifting and low cost of operation. The advantages shown in all these respects by the steam motor, he said, had been realized for years by operators of steam cars, and the author, in discussing their hill-climbing capacity and acceleration in Par. 6, was not quite accurate in saying that they were hitherto unknown. Rather, they had hitherto been unappreciated.

The author apparently preferred the water-tube boiler to the cylindrical or drum boiler with vertical tubes, and mentioned in Par. 11 a contraflow forced-circulation boiler as being commendable. One advantage of the drum boiler was that the water surface was in one continuous sheet, which facilitated the release of steam, with the minimum of priming, and without the "geyser" effect likely to occur in tube boilers in which the water surface was cut up into many small elements. The drum boiler also had the largest water capacity, which was desirable in that it enabled the storage of the maximum amount of heat energy and also gave stability to the steam pressure. From the point of view of performance the drum boiler was probably better than any other, and with respect to safety it might be said that

[1] Lewis Institute, Chicago, Ill.

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explosions were unknown. He thought the author hardly fair to the makers of the one steam vehicle that had successfully stood the test of time, when he said that certain types that were in fact merely proposed or possibly in course of development exhibited a very great advance over older constructions. The proposed new constructions might turn out to be superior to the old, but the fact had yet to be established.

The author was also hardly justified in stating in Par. 14 that the system of fuel feed employing pressure in combination with a pilot light was "steadily being displaced in the more modern designs," in view of the fact that this system now had exclusive possession of the market after having stood the test of years of service. The pressure-and-pilot system had the great advantage of regulating the fuel, that is, turning it up or down, at all times in accordance to the load. The other systems turned the fuel all off or all on. Surely it was better to keep the burner going continuously and at the lowest rate the load would permit, than to work the boiler intermittently at maximum and zero loads; in the all-on and all-off type of control the boiler never made steam except at an overload rate, and the superheat must inevitably fluctuate considerably.

The author expressed a preference for steam pressures of 400 to 500 lb. gage, on the ground that the temperatures accompanying higher pressures were destructive to the lubricating oil. However, the increase of temperature with increasing pressure was extremely slow with steam, the rise from 500 to 600 lb. being only about 19 deg. fahr., and from 600 to 700 lb. only about 15 deg. There was no particular objection to the use of higher pressures, and within certain limits it led to a more compact construction of the motor, which was desirable. The real reasons, however, were because it widened the range of throttle control and because it augmented energy storage.

EDWARD N. TRUMP emphasized the advantages of using uniflow engines in the steam automobile. The economy curve of this engine is very flat, but the very high initial pressure gives such a high initial torque, at least double the ordinary running torque, that it is possible to start a uniflow-engine steam truck under conditions under which it would be impossible to start a gasoline truck.

Many people are interested in the steam truck because it would enable them to start a load and keep the truck going under conditions absolutely impossible with the gasoline engine

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THE AUTHOR. For some time the author has been brought into contact with a number of groups of engineers and manufacturers engaged in systematic development work in connection with boilers, combustion systems and steam motors designed for automotive service.

This work is of great value and holds forth promise of most gratifying success. The object of the paper was to provoke discussion among these varied interests in the belief that such discussion at this time would be of value to the cause of steam. It was natural that the established builders should be more ready with discussion than the experimental workers, and that there should be some tendency to decry methods not proved by the test of time. To discussion of this nature, however, the author would reply generally that the superior fitness of the steam motor for certain classes of automotive service is unquestioned. In spite of this there has been a steadily decreasing percentage in the use of the steam motor in this field. Therefore the future of the steam motor in a broad way would seem to rest with these newer methods or with changes which their influence will force in the older practice. It is the author's position that this newer work holds forth promise that it will have permanent value in enhancing the position of the steam motor.

In reply to Mr. Younger, it is to be said that while decrease in the quality of gasoline has constantly been coincident with increase of efficiency of carburetion, there has been no improvement in carburetor design which has lessened the user's desire for the high-test gas of earlier days, or which disproves the author's statement that we have reached a position where we must burn oil fuel by methods other than carburetion and burning in an internal-combustion engine.

It is a fact that kerosene is so widely distributed that it is wise for designers of combustion devices to use it as a fuel, but it is not true that most of the experimenters have "found it necessary" to use this fuel. Any clean fuel, from Diesel oil to gasoline, may be and is used with entire success.

Mr. Younger correctly states the author's position that the steam motor has superior fitness for automotive service, especially in the commercial field, but the author believes that he is in error in saying that there is no demand for steam and unhappy in the examples which he cites. It is true that there is no demand for any kind of a steam unit, but there is a tremendous demand for such a unit as the author indicates. It is true that light gasoline tractors designed for

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plowing are displacing 20,000-lb. locomotive-type tractors designed to supply power for threshing, but it also is true that almost any ten-year-old steam tractor will be found to be in better condition and to have cost less for repairs than any three-year-old gasoline tractor on the market. Now, suppose that this same reliability and upkeep are combined in a light modern steam tractor designed for plowing, say, a tractor lighter in weight and simpler than a gasoline tractor and which will plow more acres of land on one gallon of fuel oil than any large gasoline tractor will plow on one gallon of gasoline, who will question the demand for a steam tractor of this nature? Such tractors are in experimental operation today and trucks embodying the same ideas are now in commercial service.

The author fails to see that the failures of ten years ago, which Mr. Younger cites, have any bearing on the success of today.

There are many conflicting statements as to operating costs of gasoline trucks and much depends on what Mr. Younger calls "surprisingly low." But the author does not consider that an upkeep cost of 45 per cent of the gross income can be called low, yet this is the average upkeep, not including any burden or overhead, of a typical trucking company which operates 150 high-grade trucks in city service. The company is efficiently managed, owns its own repair shops, which are directed by a trained and experienced automotive engineer, and the chief cause of this enormous upkeep cost is the inherent unfitness of the gasoline motor for very heavy trucking service.

In reply to Mr. Sturgess and regarding the multi-cylinder motor, it may be true, as he implies, that the two-cylinder double-acting motor will be the standard type. The chief disadvantage of the horizontal motor of this type is that it cannot be balanced. Its use is therefore confined to that of a slow-speed motor so connected to the rear axle that the effort of the unbalanced inertia forces is not transmitted to the sprung weight of the chassis. Opposed to this are the double-acting two-cylinder V-type and the four-cylinder single-acting V-type, both of which are balanced and may therefore be operated at much higher speed and mounted on the chassis in the usual way. The single-acting type with poppet valves has the further advantage that it is admirably suited to manufacture in existing automobile shops, using existing tools and modern methods.

Regarding the uniflow motor, the greater part of the experimental work now in progress is being carried on with this type of motor. This is partly because of the much higher economy of the true uniflow

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as compared to the contraflow type, and partly because it is a poppet-valve engine and designed primarily for high pressure and high superheat. Again it is a question of type.

If we assume the commonly used working conditions of 600 lb. pressure and 150 deg. superheat, then the thermodynamic advantage of using an early cut-off and expanding down from full boiler pressure in a uniflow cylinder is, roughly, 50 per cent as compared to the usual system of throttling to a steam-chest pressure of 100 lb. and developing the same power on a later cut-off. This becomes evident from a comparison in the two cases of the percentage of energy available when referred to the Rankine cycle. For example, the steam consumption of an ideal engine working on the Rankine cycle (or Clausius cycle) with complete expansion from the two pressures considered would be (at 150 deg. superheat) 15 lb. per i.hp-hr. expanding from 100 lb. pressure and 8.5 lb. per i.hp-hr. from 600 lb.

The true uniflow engine will benefit by the higher pressure, due to smaller clearance volume required, at better cylinder efficiency than the common type usually used at lower pressure. But assuming the same cylinder efficiency in both cases at the figure given by Professor Carpenter in his test of the White steam car, or 68 per cent, the actual steam consumptions for the two cases are 22 lb. at 100 lb. pressure and 12.5 lb. at 600 lb. pressure. These figures have been closely approached in actual performance of motor cars and trucks.

The author understands that the "grave difficulty" referred to by Mr. Sturgess is the greater variation in torque due to the higher pressure and short cut-off of the uniflow type; or, in other words, the probable necessity of a flywheel of moderate size.

The author agrees with Mr. Sturgess as to the disadvantages of the usual design of flash-type boilers, and especially to the "geyser-like" action with which many of them are afflicted, but for commercial as well as automobile service there is great promise in the type which Professor Carpenter has named the continuous-tube type, one essential of which is a positive, pump-controlled water and steam circulation. The author regrets that he is not at liberty to present full efficiency figures or tests on boilers of this type, but he may say that they are higher than that of any boiler, large or small, of which he is personally informed.

The author expected disagreement with his statement regarding a combustion system using a Bunsen type of burner. Much has been done with this type within the past few months and its advocates claim that all of the disadvantages which obtained in the past have

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been eradicated. He adheres to the statement that other types of burner are used in the majority of the newer designs now coming forward, and this paper deals with the present and future rather than the practice of the past.

Mr. Staley states that he disagrees with the author as to the advantages of the uniflow type of engine and gives his reasons as follows: "First, owing to early exhaust closure, an economical non-condensing uniflow engine has a high compression. With the low steam-chest pressures and variable cut-off demanded in automobile operation valve lifting will occur."

To this the author points out that low steam-chest pressure is not demanded, neither is it desirable except in the special case of an engine with no flywheel. He sees no objection to the use of a flywheel, certainly none to justify the sacrifice of economy which throttling to a low steam-chest pressure entails.

In his second statement Mr. Staley proposes two methods of relieving high compression and proves that each is bad. The author would point out that Mr. Staley's error lies in selecting these men of straw which he demolishes. The true way to relieve this excess compression is not to have any, for if the steam is held in the steam chest at full boiler pressure, as economy demands, then at these high pressures the clearance becomes as low as is mechanically good practice.

Mr. Staley is clearly in error in his third objection. It is not true that a lower m.e.p. involves a larger engine, heavier and more expensive. It may involve a greater cylinder diameter on account of the lower pressure per square inch, but that is all, and it is not conceded that the m.e.p. is necessarily lower.

Mr. Staley's fourth point is that an early cut-off produces a rough-running engine, which is probably correct if the engine has no flywheel.

Mr. Staley later states that the use of superheated steam in a contraflow non-condensing engine gives an economy as good or better than is obtained with a uniflow, as has been amply demonstrated by test. To which it may be said that while an engine in which the piston closes the exhaust ports is often called a uniflow engine, it is not a true uniflow and unless properly jacketed and fitted with a long piston it will not give better economy than a contraflow engine. The author understands that the tests to which Mr. Staley refers were not made with a real uniflow engine, but were made with a slide-valve engine having central exhaust ports closed by the piston.

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The author recognizes the merits of the fire-tube boiler and concedes its safety for this service, but he does not admit that it is inherently as fine a type for this service as the water-tube and he ventures the opinion that in the coming contest of types the latter type will win.

In closing, the author would make a plea for more publicity on the part of designers engaged in developing experimental types. He maintains that there is a great public need for steam-driven trucks and tractors, and that steam power offers the only adequate remedy for the evils he has pointed out. He believes that the designers should not in these times design each merely for his own firm and from his own standpoint, but that this is a time for all to come forward and for each to give the engineering world the benefit of his experience, to the end that the public may so much the sooner benefit by the combined results of their labors.

The steam car, or truck, or tractor, will not be the work of one man or one firm — it will be the combined work of all workers in the steam field, and the sooner this combination is effected the better it will be for every one.

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No. 1610

PREVENTABLE WASTE OF COAL IN THE UNITED STATES

By David Moffat Myers, New York, N. Y.
Member of the Society

By employing proper operating methods in boiler plants it is easily possible, according to the author, to save at least 10 per cent of the coal now burned for steam-making purposes. Such a saving would release cars for other service equivalent, say, to the coal-carrying capacity of the Pennsylvania Railroad lines east of Pittsburgh, equal to 1,000,000 fifty-ton carloads per year, and the direct money saving to the industries would be around a quarter of a billion dollars, figuring the coal at $5 a ton.

The object of the paper is to open a discussion which, it is hoped, will lead to the formulation by the Society of definite recommendations of means for the reduction of the present great preventable waste of fuel in our industries, largely through faulty, careless and uninformed operation of boiler plants, and to the offering of the services of the Society to the Government for the organization, furthering, and, as far as possible, execution of the plan which may as a consequence be adopted.

AS a means of far-reaching economy the Government of the United States should at this time apply intelligent and direct-acting efforts to the conservation of fuel at the industrial plants which are responsible for its greatest consumption. It is unnecessary before a body of engineers to show proof that coal is wasted in vast quantities in the boiler furnaces of our plants, to feed which it is mined and distributed at a high and ever-increasing cost of labor and material.

2 The mining and distribution of the coal have been placed under the supervision of the War Coal Board in order more nearly to meet the crying needs in these directions, to use the railroad facilities more efficiently so that the present car shortage may be minimized to the greatest possible extent and to apportion the coal in quantity and to uses deemed most expedient.

3 While this organized effort to bring about efficiency in the

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production and distribution of coal is being made, no parallel measures have been adopted to bring about a normal and practicable efficiency in its use. The hundreds of large plants which are consuming fuel wastefully, in many cases more wastefully and carelessly than ever before, are directly and needlessly causing a large fraction of the existing car shortage. They are overloading the already strained capacity of the railroads; they are rendering slower and more difficult the transportation of food and other vital commodities, and in short they are simply counteracting the measures of efficiency in production and distribution which have elsewhere been established.

PREVENTABLE WASTE OF FUEL

4 The preventable waste of fuel in the boiler furnace of one steel mill which I investigated amounted to 40,000 tons per year, which at $5 a ton would cost $200,000. This was a comparatively modern plant. The efficiency of boilers and furnaces in a 14-day test was 55 per cent. The load factor was unusually favorable to high efficiency and could readily be raised to 70 per cent or over. This is only one example and there are many more extreme cases. In one hand-fired plant the evaporation was raised from 6 to 9 lb. in a few days of instruction and continuously kept close to this higher mark with the help of coal and water measurements which were inaugurated. The saving was due exclusively to instruction and consequent better operation.

5 The saving or wasting of one-fourth of the coal consumption of any industrial plant, depends entirely upon the efficiency of its operating management. Let me emphasize that this fraction of the consumption relates exclusively to the *boiler* plants, i.e., the production of steam; and does not include the large economies possible in connection with its distribution and use.

6 For well-known reasons the boiler plant offers the more lucrative field for producing economies, and these with a minimum of alteration in physical equipment.

7 Under present conditions a plant which carelessly operates at an efficiency of 40 to 50 per cent, receives from the Government the same consideration in the delivery of coal as the one whose efficiency is 70 to 75 per cent. This obviously is unfair and wasteful.

8 The Government hands over, say, 200,000 tons of coal a year to a plant owner, but asks for no accounting as regards its consump-

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tion, nor any questions as to the amount of steam it is made to produce. There is nevertheless an equivalent amount of steam this fuel is capable of generating and it can and should be made to produce that quantity.

9 If people threw away food products as hundreds of plants are literally throwing away fuel, the waste would receive attention and public condemnation. Wasting coal makes food more expensive and more difficult to obtain.

10 There is no doubt that very important economies in the use of food have already been effected by the educational campaign with which we are familiar. These economies are largely the result of educating the ultimate consumer. The requisite propaganda does not attempt to teach the intricacies of food chemistry or the complex action of the gastric juices. It spreads practical information concerning the efficient use of foods and their respective values and methods of preparation in such simple and convincing manner as to be understood and practiced by the women all over the United States. It places this information where it will be applied.

11 The object of this paper is to open a discussion which, it is hoped, will ultimately lead to the formulation of definite recommendations of means for the reduction of the present great preventable waste of fuel in our industries; to direct such means principally toward the elimination of that portion of the present waste which is due to faulty, careless and uninformed operation of plants; to forward these recommendations to the proper governmental authorities as an official communication of this Society, and to offer to the Government the services of the Society for the organization, furthering, and as far as possible the execution of the plan which may as a consequence be adopted.

CONSERVATION METHODS

12 In general, there are, I think, two plans of operation worthy at least of consideration. The one might be termed the autocratic method. This would involve the use of authority to compel coal consumers to execute such measures of economy as the proper authorities might prescribe for any given case, limits to be set as to expense to the user. Such limits might be in terms of a percentage of his present yearly coal bill. Alterations should be directed chiefly, as previously implied, to purely operating improvements. Many objections would probably be made by consumers against this plan, but once in effect the majority would no doubt realize its pecuniary

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advantage to themselves. But its tendency may be too strongly opposed to democratic principles.

13 The other plan would be largely an educational one, in which patriotism and efficiency would furnish the motive forces required.

14 The teaching must be accomplished with the utmost simplicity and directness. Above all it must be in such form as to be readily comprehended and applied. This is a big task, but with the technical and executive ability represented in this Society, these things may be accomplished.

15 The requisite information must reach the owners and managers of industries, and there must be simple instruction sheets for the engineers and firemen. The vital importance of daily accurate records of coal and water must be taught and information given regarding practical appliances for automatic measurements of both.

16 Blank forms might be sent in advance to plant owners in order to be advised by them, first, whether they would be willing to coöperate with a governmental organization offering to assist them in reducing their coal consumption, and second, to obtain such data as to size, type, equipment, operation and fuel consumption of the plants as would enable a classification which would permit a government board of experts to send such instructions as would include the information needed for any one class of plants.

17 This work would be very greatly aided by a staff of experts ready to visit plants when so requested by owners, and make investigations and recommendations and keep in touch with the progress of economies. Included in such a staff must be men intimately familiar with practical operating economies, whose duties would be the delivering of lectures or talks which should be planned so as to reach directly not only managers and owners of the industries, but also the chief engineers and firemen of the boiler plants. This feature of the plan, by itself, would undoubtedly result in great good.

18 The U. S. Bureau of Mines has for a number of years engaged in obtaining and disseminating scientific information regarding the mining and consumption of coal, and the results of the work have been of great value to technical engineers who are able to use and apply it. It is evident that we now require an extension of the idea of education, but in such form as directly to affect the men who run the boiler plants of our country, for in their hands is the saving or wasting of one-fourth of the fuel which they consume.

19 Six hundred million tons of coal were mined in the United

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States last year. It is predicted that 700,000,000 tons will be mined this year, and next year's production will likely be still greater. Of this quantity approximately 67 per cent, or 469,000,000 tons, will be burned for steam-making purposes on land, assuming the same percentage consumption for steam production as existed in the year 1915. (See Table 3, Items 5 and 6.)

20 The saving or wasting of one-quarter of this coal, that is, over 117,000,000 tons, depends upon the efficiency with which we operate our boiler furnaces. If we actually saved by proper methods only 50,000,000 tons per year, this economy would result in freeing for other important service the use of 1,000,000 fifty-ton freight cars per year. The significance of such an economy may be realized when it is stated that the number of cars thus released for other service would be equivalent to 15 per cent more than the combined yearly coal-carrying capacity of the Baltimore & Ohio and Southern Railway systems; approximately equal to that of the Pennsylvania Railroad system on lines east of Pittsburgh, or $1\frac{2}{3}$ times the number of coal cars hauled by the Norfolk & Western. (See Table 4.) The direct saving to our industries would be $250,000,000 worth of coal per year, if figured at $5 per ton.

21 This saving would be $\left(\frac{50,000,000}{469,000,000} = \right)$ 10.65 per cent of the coal now burned for steam production. It is impossible to state the present average efficiency of boilers and furnaces, but I have personally spent sixteen years of concentrated study in the investigation and improvement of steam and fuel conditions in factory power plants, and I have never visited a plant of this class where a saving in coal of at least 10 to 12 per cent could not easily be made. The poorer the conditions found the easier it is to make an attractive saving in fuel.

22 Table 5 shows to what point the efficiency of a plant must be raised to obtain the saving of 10.65 per cent upon which these economies are based. The poorly run boilers would of course be susceptible to the greatest improvements. Hundreds of boiler plants operate at no greater than 58.07 per cent efficiency and it is a comparatively simple matter to bring them up to an efficiency of 70 per cent or higher. The latter would result in a saving of over 17 per cent of the coal. Thus the large improvement possible in the less efficient plants would tend to balance or more than balance the smaller economies to be obtained in those which are better operated. In short, it is my opinion that the average saving of 10.65 per cent (corresponding to

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1,000,000 fifty-ton carloads per year) is a conservative estimate of what can be accomplished by a well-directed and properly organized movement in the direction I have proposed.

TABLE 1 TOTAL COAL PRODUCTION, BITUMINOUS, LIGNITE AND ANTHRACITE, YEAR 1915

	Net tons	Per cent
1 Bituminous and lignite	443,462,509	85.2
2 Anthracite	76,906,431	14.8
3 Total	520,368,940	100.0

TABLE 2 PERCENTAGE DISTRIBUTION OF BITUMINOUS COAL AND LIGNITE PRODUCED IN THE UNITED STATES AND IMPORTED IN 1915, BY USES

	Per cent
1 Railroad fuel	28.0
2 Steamship bunker fuel — Tidewater	2.0
3 Steamship bunker fuel — Great Lakes	0.3
4 Manufacture of beehive coke	9.3
5 Manufacture of by-product coke	4.3
6 Manufacture of coal gas	1.0
7 Domestic and small steam trade	16.0
8 Industrial steam trade	33.0
9 Exported	4.0
10 Steam and heat at mines	2.0
11 Special uses	0.1
12 Total bituminous and lignite	100.0

NOTE. — Imports were only a little over one-tenth of one per cent and are therefore neglected.

No information is available for complete classification of the distribution of the anthracite, but it is estimated in the report on Coal in 1915[1] from which Tables 1 and 2 are made, that 50,000,000 net tons of anthracite were used in 1915 for "heating households, apartment houses, hotels, and office, school and other buildings." This leaves about 27,000,000 net tons or 35 per cent for industrial uses, principally steam making. If we eliminate households we may assume that 25,000,000 tons of the 50,000,000 tons are used for making steam, so that of the total 77,000,000 tons of anthracite we may say that 52,000,000 tons, or 67.5 per cent, are used for steam production.

23 If we do not limit our field of action to coal used merely for steam generation, but extend it to include a consideration of the economy with which the steam itself is utilized and applied, there is no doubt in my mind that the above-predicted saving could be

[1] Coal in 1915, by C. E. Lesher, published by the U. S. Geological Survey; Part A on production, Part B on distribution.

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TABLE 3 COAL USED ON LAND FOR STEAM PRODUCTION IN PERCENTAGE OF TOTAL PRODUCTION

	Per cent
BITUMINOUS:	
1 Railroads, item 1, Table 2	28.0
2 Domestic and steam trade, assume only one-quarter of item 7, Table 2	4.0
3 Industrial steam trade, item 8, Table 2	33.0
4 Steam and heat at mines, item 10, Table 2	2.0
5 Total bituminous	67 0
ANTHRACITE:	
6 To steam making	67.5

Hence it may be assumed that 67 per cent of all the coal produced is used for making steam on land.

TABLE 4 COAL CARRIED BY RAILROADS DURING THE CALENDAR YEAR 1916

Railroad		Tons	Equivalent 50-ton carloads
1 Baltimore & Ohio, exclusive of their fuel coal		33,615,581	673,000
2 Pennsylvania Lines east of Pittsburgh, exclusive of non-revenue shipments	Anthracite	10,715.145	
	Bituminous	43,044,906	
	Total	58,760,051	1,075,000
3 Norfolk & Western, total revenue shipments		30,653,755[1]	600,904[2]
4 Southern Railway System, 12 months ending June 30, 1916, exclusive of that used for own purposes		9,819,190	196,000

[1] Net tons. [2] Cars actually used from report, which would be 51 tons average per car.

To save 10.7 per cent of the coal consumption necessitates the raising of any combined efficiency of boiler and furnace from that shown under Old Efficiency in Table 5 to the corresponding value under New Efficiency in the same table.

TABLE 5 INCREASES IN COMBINED EFFICIENCIES OF BOILER AND FURNACE NECESSARY TO EFFECT A 10.7 PER CENT SAVING IN COAL

Old efficiency, per cent	New efficiency, per cent	Old efficiency, per cent	New efficiency, per cent
44.67	50	62.54	70
49.14	55	67.00	75
53.60	60	71.47	80
58.07	65	.....	.....

Saving of coal with same output of steam

$$= \frac{\text{New Efficiency} - \text{Old Efficiency}}{\text{New Efficiency}}$$

and

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Increase of steam production for same coal

$$= \frac{\text{New Efficiency} - \text{Old Efficiency}}{\text{Old Efficiency}}.$$

doubled, so that we might save 2,000,000 fifty-ton carloads of coal a year. There is, for instance, widespread ignorance to a surprising degree in regard to the value of exhaust steam in heating and process work. The coal-consuming public should be taught that a heating system which requires 100 boiler horsepower may insert a steam engine between boiler and heating main and obtain nearly 100 mechanical or electrical horsepower in addition to the required heating for about the same consumption of fuel. No account has thus far been taken of other primary uses of coal such as coke production, which consumes about 14 per cent of the output of our mines (Table 2, items 4 and 5), and coal-gas manufacture, domestic purposes and miscellaneous. Additional economies could undoubtedly be effected in these applications.

24 There are of course certain uses for which coal is consumed which are not primarily or essentially productive in their nature. A consideration of these should be included as a phase of the work of conservation of the fuel for the more serviceable applications.

25 Our steam plants are under the immediate management of chief operating engineers. The examination requirements for licenses in this profession call for practically no knowledge of steam and fuel economics. These examinations deal chiefly with matters of safety, repair and maintenance of equipment and neglect almost entirely the subject of coal economy. This is a very serious defect in our present system and is directly responsible for a large preventable waste of fuel.

26 The mining and distribution of our coal supply, the regulation of prices and the adjustment of financial and labor problems have already been placed under official administrative attention. But no parallel measures have been adopted looking toward reduction of waste in connection with the utilization of this coal. We are now threatened with a serious coal shortage due chiefly to the present overstrained carrying capacity of our railway systems. A large preventable and needless waste of coal exists at the points of its consumption. We may save from one to two million carloads of coal annually if we will apply to the problem the executive and technical ability which is available in this Society. The economies developed by this saving would be far-reaching in many directions and their need is urgent if not vital.

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27 The work involved in a general program such as I have very briefly suggested will undoubtedly be undertaken. Its success or failure will depend chiefly upon the kind of men who may be selected for its planning and execution. This Society is exceptionally well-equipped with trained engineers and executives specifically suited to the requirements of this task. As a Society we have already contributed importantly to the welfare of the public. May we not add this service for the benefit of our country and humanity?

DISCUSSION

WALTER N. POLAKOV (written). Of the author's two plans the first one is so unfortunately worded as to create prejudice against it. It reads, ". . . the use of authority to compel coal consumers to execute such measures of economy as the proper authority might prescribe in any given case." The plan really means the abolition of privilege to waste fuel in inefficiently conducted plants, by giving priority in coal deliveries to those who prove that they do not use it efficiently.

This priority can be determined by:

1 Rating by experts (nominated by the national engineering societies and supported by public opinion and the Government) of plants in the indispensable industries which are entitled, because of coal-saving methods in use, to priority in coal supply.

2 Receiving of applications by a special service bureau of The American Society of Mechanical Engineers from the low-rated plants for assigning the expert help.

3 Serving the needs of such inefficient plants by offering services of recognized experts in power-plant management for direction of the work.

4 Organizing a staff of steam, electrical and combustion engineers, whose members will be assigned to carry out the work in the plants of the applicants under the direction and supervision of experts.

5 Charging for such services an adequate compensation to cover the expenses involved (salaries, traveling and office) but no profit.

Mr. Myers's second plan, "an educational one, in which patriotism and efficiency would furnish the motive forces required," in my opinion is doomed to failure for the following reasons:

a Teaching efficiency by a correspondence-school method will accomplish little good, is incompatible with the professional dignity of this Society and lacks the personal touch.

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b Endless variety of equipment, grades of fuel available, personality of men, nature of load, climatic conditions, etc., make the preparation of "simple instruction sheets for engineers and firemen" impossible, and if these are made they are so general as to be useless.

c No instructions of real value could be given unless examination of the plant were made.

d Keeping records, logs, etc., necessitates instrument equipment and measuring devices. All of this is good only when the data are used and interpreted by a trained man and this is done continually. Too many plants have no instruments at all; most of those that have, keep them as ornaments due to the lack of proper organization.

e If the regular employees have failed to secure high efficiency it is not because of the lack of "circularized education" but chiefly on account of (1) lack of time to carry out investigations and tests, all the time being absorbed by routine duties; (2) absence of instruments, facilities or encouragement; (3) lack of experience in this highly specialized line of research work.

f The education should begin with the owners and managers, not with the firemen.

g The very principle of "teaching" and "instructions" given to manufacturers and plant owners by the Society is undemocratic and un-American. They do not want or need to get something for nothing. Producing for the country but not without profit, they prefer to pay for what they get if the benefit is commensurate with the expense.

h "Educational" talks and circulars usually degenerate into debating societies wasting time needed for deeds.

i Any half-measures with good intentions falling short of accomplishing valuable results are dangerous, as they chloroform the public conscience.

To sum up, the problem is to be solved by groups and individuals available through this Society for the service of those who know how more power can be gotten out of a pound of coal. There is no necessity of compelling plant owners to improve their methods, since in such a step lies their self-preservation. But there is an urgent necessity from the national standpoint to conserve the fuel by preventing its waste by ignorance or indifference. The valuation of plant methods to establish ratings for priority in coal deliveries is therefore recommended.

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PERCIVAL R. MOSES,[1] in a written discussion, pointed out that an improvement in efficiency could be obtained by coöperation between central stations and private power plants, which, he believed, would effect a saving of fuel greatly in excess of that procurable by improvement of the private plants.

Under this plan the private plants would be shut down during light-load periods (say 10 p.m. to 6 a.m.) in the heating season and also from May 1 to November 1, obtaining their current for lighting and power from the central station. During the season when steam is required for heating, it is manifest that the private plant utilizing practically all of the available heat in the steam is much more efficient from the community standpoint than the highly developed central station which wastes 85 to 90 per cent of the energy in the steam in the condenser water.

To obtain maximum results the private plant should be encouraged to supply steam for heating purposes to its neighbors and to supply all the electricity it is capable of supplying up to the limit of the amount of steam it can utilize as low-pressure steam. Such plants would in effect become steam sub-stations of the public utility company.

All that would be required to effect the great economy obtainable through this plan would be a suitable central-station rate for off-peak current. The advantage to the community would be that from three to four times as many kilowatt-hours would be obtained per ton of coal burned as compared with present operations.

EMMETT B. CARTER wrote that he agreed with Mr. Myers's idea of a campaign of education among the firemen, but thought that we should feel some hesitancy in recommending the establishment of a bureau of such magnitude as would be required to carry on the work proposed, because we lack the men. The bureau will mean a very large force of men, valuable technical men, who can ill be spared now from other important work.

It is this same lack of intelligent men which is causing the waste of so much of our coal in the first place. Almost one-half of the coal being consumed for steam is used by the railroads, and the great problem confronting the railroads now is not how to burn the coal economically, but how to get the men to burn the coal at all.

C. R. WEYMOUTH (written). In my opinion the possible saving in coal consumption due to increased boiler efficiency will be mate-

[1] 366 Fifth Avenue, New York.

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rially less than stated by Mr. Myers. The biggest coal users of today are the mammoth public-utility companies, who have already been compelled to employ the best brains available and boiler-room efficiency engineers as well to maintain their economy of power production at a maximum, and it is inconceivable to me that they can save 10 per cent in their fuel consumption, or even half of that amount. There are no doubt many smaller users of power where the yearly bill is such that they are not warranted in employing an efficiency engineer, and in these plants a saving would be possible if expert services were available.

I suggest the formation of a committee of engineers representing the various classes of coal users, and familiar with this subject, to make a preliminary canvass of the situation from the data available, including census reports. The findings of this committee would indicate the extent to which this subject should be further investigated and recommendations made to the Federal Fuel Administrator. This investigation should also cover the question of availability of engineers and fuel experts to give instructions as to the better firing methods, should it be found that a large fuel saving is possible. My observations indicate that nearly all mechanical engineers are busy in some department or other in connection with the war, or vital industries, and that comparatively few men will be available to carry on a fuel-saving campaign, even should it be found that such a campaign might give beneficial results.

Whether the committee's findings indicate that a large fuel saving could be made, all engineers will agree that a campaign of some character should be made to reduce the waste of coal. Mr. Myers's suggestion that instructions be issued to firemen in simple language is a very timely one. We have had textbooks and technical papers almost without limit prepared for the benefit of technically trained men; but there has never been, to my knowledge, a suitable primer giving the elementary principles of combustion and the essential knowledge for a fireman. The preparation of such a primer could be well undertaken by the committee proposed, and it could be given wide circulation with surely beneficial results.

Any attempt to curtail the coal supply as a means of compulsory increase in boiler efficiency would, to my mind, lead to a chaotic condition. Whatever is done must be done voluntarily, at least initially. Variations in load factor, rate of demand, etc., complications of red tape, are such that any limitation of the quantity of

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coal supplied a given user would likely give rise to regrettable complications and curtailment of necessary output.

While there are minor improvements in boiler plants which can be made at this time, it must be borne in mind that the present-day trend in increased economy of fuel calls for higher steam pressures, higher degrees of superheat, larger prime movers, centralized generating stations — things which, if now generally put into effect, would immediately tax certain manufacturing facilities which should be left undisturbed for the production of the war's necessities.

A. F. GRAVES[1] wrote giving brief particulars of what his company had done in increasing the economy of a boiler plant already high.

An instrument board was installed in the boiler room, with water- and steam-flow meters, temperature recorders and draft gages. With this means of studying all conditions, series of tests were run on the boilers for the purpose of finding the most efficient operating conditions at all loads, and printed instructions issued to the firemen so that they could always maintain these conditions. In this way a saving of about 12 per cent of the coal had been made, and possibly some ammunition factory was using that very coal to make the rifles that would help to put our boys "over the top."

It seemed only fair to rate a plant for its wastefulness as well as its economy, and the plant which could burn the coal most efficiently should have priority in coal deliveries.

R. K. GOODLATTE[2] wrote that he believed great good would be accomplished if the Society, backed by the Fuel Administration Board, would inaugurate an active campaign toward the end of preventing waste of coal in industrial plants.

He suggested publishing posters giving simple instructions for hand and stoker firing, cleaning of fires, watching scale prevention, coal weighing, water measuring, etc. These instructions could be made vital and forceful by periodical visits by practical men with authority to enforce them, if necessary, under threat of coal-supply regulation.

E. P. ROBERTS (written). I would suggest that more attention be paid to saving fuel used for heating by "sensible heating," which is heating that satisfies the senses rather than the thermometer,

[1] Strathmore Paper Co., Mittineague, Mass.

[2] T. R. Goodlatte & Sons, Delawanna, N. J.

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that is, the dry-bulb reading. The drier the air, the cooler the person, due to evaporation; therefore the thermometer is not an indicator of the body temperature. Sensible heating provides desirable humidity and the result is greater comfort and health, less depreciation of furniture, and less fuel.

Lessening the smoke requires a careful study of all conditions affecting combustion and therefore results in fuel economy. In addition to the direct saving there is the even greater saving resulting from lessening the damage done by the soot. The direct damage done by soot from bituminous coal, per ton, is not less than from one to two dollars.

Recent literature relative to saving coal has had frequent reference to the fact that the bituminous coal furnished in 1917 ran higher in ash than previously, resulting in a greater number of cars being required to transport a given number of heat units, and in lessened value of the coal — due to the fact that the obtainable fuel efficiency decreases more rapidly than the ash percentage increases. This fact is important, but there is another fact, or three interrelated facts, that are of even greater importance, at least in some sections where bituminous (not semi-bituminous) coal has been used for many years and certain types of stokers are in very general use. In many of these plants the fuel efficiency has been reduced from 10 to 20 per cent or more, because (1) the coal received has not been suitable to use in the type of stoker employed; (2) the setting of the boiler and stoker was not suitable; and (3) the desired rate of combustion (lb. per sq. ft. per min.) was too great for the coal. The fusing point of the ash was too low, the clinker formed could not be taken care of, and the repairs as well as the operating labor have been very high.

ALBERT A. CARY (written). The author's statement that "the saving or wasting of one-fourth of the coal consumption of any industrial plant depends *entirely* upon the efficiency of its operating management," seems to be the text upon which the balance of his paper is founded.

In order to secure the desired conservation of fuels in such plants Mr. Myers advises the services of the expert in operating management, by compulsion or otherwise; he suggests what Mr. Polakov has aptly termed a correspondence-school course, which, in the light of our experience, is not a wholly worthy suggestion.

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The expert in operating management — provided he is properly qualified and thoroughly understands his business, including the proper handling of the fuel used — can undoubtedly secure very desirable fuel savings; but his efficiency depends very largely upon the coöperation he receives from the plant owners and their employees, as well as their willingness to equip their plant with all the needed apparatus and to maintain and use them continuously after the expert concludes his work.

Aside from the training of a boiler-room force by such experts, there are other matters which cannot be relegated to a second place of importance in considering the requirements for reducing the waste of fuel.

Proper furnace design and construction, adapted to the use of the particular kind of quality of fuel used, furnish unquestionably the very keynote of the whole question of fuel conservation. By the term "furnace design" in a boiler equipment is included not only the furnace with its equipment, but also the entire boiler setting, flue and draft-producing equipment.

Let us concentrate with greater earnestness upon the design and construction of our furnaces. Let us study our available refractories for furnace linings with greater care, as well as the high-temperature cements, the mortar used, and the red bricks used to enclose our settings.

After equipping our plant with proper furnace settings which are adapted to produce the highest possible efficiency with the particular fuel available, our expert in operating management can come into the plant and do his most efficient work by instructing the men how to operate the furnaces in the most efficient manner. He can train them in the use of the instruments required to keep the plant constantly in its highest operating condition, and there are many other needed duties requiring his attention to produce the most economical and requisite results which will reduce the amount of fuel and labor required.

Turning now to the personal factor which enters so strongly into our fuel-economy problem: In our larger central power stations the men who handle the coal and operate the boilers have been well trained, and they generally know that they *must* obey instructions or lose their jobs. In the smaller plants we find a wide variety of firemen, some of whom are splendid fellows, who are anxious to learn and who take a pride in their work; while others strongly resent the intrusion of an outsider to show them how to operate

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their plant more economically. This latter class is responsible for the largest wastes of fuel occurring in steam plants.

Many of these men are certainly not fitted for the position of firemen, and, unfortunately, many employers seem to think that the only qualifications needed are that they be strong, husky men who can stand up before a hot fire and shovel in a lot of coal every time the furnace door is opened, and then pull out the ash and clinkers from the grates or ashpit once a day.

In order to stop our enormous coal wastes in industrial and other plants, these so-called firemen are the first men we should get under control, and, after giving this matter considerable thought, I have reached the conclusion that there is one way in which this can be done practically.

To meet the present emergency, I propose that the War Coal Board take the necessary measures to bring all the firemen in this country under their control by requiring each of them to take out and hold a United States license.

The applicants for these licenses must show some qualifications which would entitle them to hold such privileges, but it is doubtful whether it would be possible, at the beginning, to have all of these applicants examined before qualified examination boards.

Future applicants should be required to pass an examination before such boards, and qualify in a satisfactory manner before receiving their licenses.

By this means a better class of men will gradually displace the many fuel-wasting incompetents who are now disgracing the firemen's trade.

This process would thus tend to weed out the incompetent men who are keeping good, deserving and competent firemen out of jobs which belong to them, and thus, eventually, the status of the firemen would be raised, and their better fuel-saving work would merit them a higher rate of wages, which the owner could well afford to pay out of such savings effected in his steam plant.

On the other hand, the stubborn, unpatriotic, penny-wise and pound-foolish owners of coal-burning plants where glaringly wasteful conditions exist — who refuse to spend a cent to better their conditions and "do their bit" in the conservation of fuel in this time of need — will meet with a rude awakening, and they will learn a lesson which will ultimately result greatly to their advantage and save them many dollars which would otherwise be hurled up their chimneys.

This proposed method is now but a war measure, but after the war

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it is bound to result in a great benefit to the owners of coal-burning plants and to the country at large.

LEWIS S. MAXFIELD (written). While the remedies suggested by the author are worthy of careful consideration, I believe that it would be more logical to seek for a suitable substitute for our high-grade coals than to try to curtail their use at this time. With the present high cost of labor and materials few power plants are in a position to undertake extensive improvements which would render them more efficient in the use of fuel. One such substitute which has never received in this country the attention which its importance entitles it to, is peat.

We have extensive peat bogs the amount of combustible matter in which, it has been estimated, exceeds that in all our known coal deposits. Peat is being used in Europe extensively as a fuel and several large industrial plants report satisfactory operation with same.

The great obstacle to the use of peat on a large commercial scale has always been the difficulty of dewatering the raw material, as peat in its natural state contains between 85 and 90 per cent of water. A part of this water may be abstracted by artificial heat or by air drying, but as it requires almost as much artificial heat for drying, as the resulting peat will generate when burned, we are therefore limited to air drying. The moisture content of raw peat can be lowered by air drying to between 30 and 35 per cent, and if a source of waste heat is available it can be lowered to about 15 per cent.

One other objection to the use of peat is that its preparation for use as fuel is confined to the summer months, thereby making necessary the storage of sufficient fuel to meet all demands during the winter. Notwithstanding that there is a certain factor of uncertainty attached to air drying due to weather conditions, it is possible to obtain with a good drying field a minimum yield of 500 tons per acre.

The most successful method of utilizing peat at present seems to be in the gas producer, which will handle peat with a moisture content of 30 to 35 per cent, this being obtainable with air drying. The Canadian Government has completed some experiments which prove that peat containing 30 per cent moisture, when used in a gas producer, will produce for every pound of peat fired from 49 to 53 cu. ft. of gas with a calorific value (calculated on a moisture-free basis) when leaving the producer of from 6030 to 6310 B.t.u. This will indicate some of the possibilities of this fuel and shows what can be expected from it in practice.

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I would suggest that the Government perfect the use of our peat deposits and deliver this fuel to the industries with instructions as to its proper use, instead of trying to make our industries do with less of the very first element of their existence. I have indicated some of the difficulties to be met in the use of peat and as its use extends other problems will come up, but they will be solved as have been those incident to the use of coal.

JOHN E. MUHLFELD (written). It seems to me that the autocratic and educational plans of procedure outlined in the paper are not in themselves sufficient for the consumers of coal to use as a basis for authorizing the capital expenditures that will, in the majority of cases, have to be made in order to produce the desired results and thereby secure an adequate financial return on the investment to be made.

Furthermore, particular stress should be laid on the fact that the more effective use of fuel should and can be made to bring about improved conditions in plant operation and labor, as well as conservation in fuel and financial returns.

Each power plant is in itself an individual engineering problem, and blanket instructions and advices cannot be of the greatest value.

There is no lack of patriotism among the coal users and the engineers of this country, and I doubt if any of them are "selling the United States short," but localized engineering improvements and supervision along practical lines for the purpose of modernizing plant equipment, and its maintenance and operation, are essential for the greatest accomplishment.

The scope of the procedure for the conservation of coal, steam-railway facilities and labor could be materially broadened by including

a The utilization of existing by-products of mining operations that are useful for steam-generating purposes, but which are now being wasted.

b The development and use of vast deposits of sub-bituminous coals and lignites lying adjacent to steam-railway lines.

The fact that one of our allies, Brazil, has recently, through the efforts of its government engineers, made possible the effective and economical use of its native coal, which has heretofore been deemed practically worthless, and thereby diminished its dependence upon imported coal for railway operation and industrial development, is worthy of our serious consideration.

The amount of useful coal now being wasted through existing

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methods of mining is great enough to more than offset the present shortage, and the reclamation and utilization of this by-product, for which labor, material and plant for mining have already been employed, in conjunction with the development of new sources of coal and lignite supply tributary to the points of consumption, are of paramount importance.

B. G. ELLIOTT (written). In the work of the Extension Division of the University of Wisconsin we have endeavored to reach the firemen and engineers in power plants by means of lectures, demonstrations, and class-study groups.

The firemen and engineers are organized in a class group and are met each week by a traveling instructor who lectures and demonstrates to them on the various problems connected with the economical combustion of fuel. The class groups usually meet for a period of eight to ten weeks. At the end of the class and lecture work, the members of the class are usually gotten together for a boiler test conducted according to the best modern practice. This test is held at one of the plants of the community, the apparatus and recording devices being sent from the University. The men are required to work up the test on specially prepared forms.

When there has not been a demand for an extended class course, the subject is presented by means of an individual lecture and demonstration on coal, its composition and combustion. The manufacturers and the business men, as well as the firemen, are invited to attend this lecture, which has proved to be a very effective method of bringing the problem before a group of men who are interested more from a financial than from a technical point of view.

MICHAEL M. PODOLSKY[1] submitted a written discussion in which he proposed a coöperative plan for solving the fuel problem, the plan to be under the control and supervision of the Government, but to be under the management of specialists nominated by the Society in conjunction with the mining, electrical and chemical engineers.

The main feature of his plan was the organization by the fuel consumers of a national society for fuel saving, the work of which would be carried on by each member contributing annually on the basis of, say, 5 to 7 cents per ton of coal consumed.

The functions of this society would be mainly to disseminate information regarding fuel saving, to provide help to the Fuel Adminis-

[1] Standard Steel Works Co., Burnham, Pa.

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trator, to recommend to the Government steps for relieving and preventing fuel shortage, to investigate and report upon new methods for saving coal, to establish special schools for firemen, to hold exhibitions and give prizes for best inventions and to aid inventors of fuel-saving devices.

The work of such a society would be under the direction of a council and would be carried out under its direction by a manager and staff.

Mr. Podolsky was of the opinion that only by the fullest coöperation between the Government, the coal consumers and the engineers on the widest scale could the fuel problem be solved. Notwithstanding the meager development of the coöperative idea in this country, the A.S.M.E. could institute such a method as described with the greatest practical results. He suggested the appointment of a committee to consider the plans presented in the paper and discussions and draw up a war plan, perhaps in collaboration with the Federal Fuel Administrator.

WILLIAM L. CATHCART (written). The United States is now the leading coal-producing country. Two-thirds of our total production is burned for steam making, with an approximate waste — as Mr. Myers very conservatively estimates — of 10 per cent, through lack of efficiency in the operation of boiler furnaces. For the prevention of this huge waste, this colossal drain on the war energy of our allies and ourselves, our Government officials may rightfully look to the membership of this Society for information and suggestions leading to a definite remedial plan.

It should be noted, too, that the economies produced from the execution of such a program would be *permanent*, lasting after the war, an enforced lesson in the value of fuel economy.

Our trouble is not unwillingness. It is simply indifference as to the value of fuel economy. And, so far as the adoption of proper remedial measures is concerned — although specifically the user will profit — it is now broadly a question of patriotism, and the managers of our industrial plants will scarcely be lacking in that.

However, there might readily be a fair number of cases in which it would be difficult to secure compliance with a mere official request to adopt methods of fuel economy. Further, the education of firemen alone scarcely seems to be a practicable solution. The pressure on those firemen for that education should come from the owners and managers of their plants. This sort of efficiency grows best from the top down, not from the bottom up.

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In the relatively few cases in which it might be necessary to bring pressure on owners or managers, Mr. Myers's comment suggests the necessary "big stick." Let the Government allow them only a quarterly or yearly amount of coal which will produce, when burned with full economy, the number of pounds of steam they require normally. If they choose to waste their allowance, let them shut down until they get their next allowance. The rigid control which the Government is now exercising, through the Federal Trade Commission, on the newsprint industry should be a lesson to such possible recalcitrants. These are war times, not the lax days of peace.

L. P. BRECKENRIDGE, Chairman of the Committee of Consulting Engineers on Coal Conservation and Publicity coöperating with the Bureau of Mines and the Federal Fuel Administrator, said that the ideas presented in the paper and discussions were excellent, but the question was whether they were immediately available. We must save coal and save it quickly, and those with suggestions should send them to Mr. O. P. Hood, at the U. S. Bureau of Mines, or to himself.

He said that Dr. Garfield, U. S. Fuel Administrator, was now preparing material to send out broadcast emphasizing the very great necessity of saving coal. Engineers should coöperate in this campaign, preferably through the representative of the Fuel Administrator in each state.

As an example of what could be done in this connection, the engineers of the Experiment Station of the University of Illinois had sent out valuable material regarding the use of the coal consumed largely in Illinois. The Fuel Administrator of Illinois should have the assistance of these men. The engineers in Connecticut, Virginia, Pennsylvania, and other states should similarly coöperate with the fuel administrators of these states, and much good would result.

Wherever engineering societies exist, some plan should be started, with the slogan "help save coal." Get in touch with the state or the city fuel administrator and offer aid. Get Government bulletins from the Bureau of Mines and distribute them at a lecture to "owners, managers and firemen." Help the local papers select facts and help them avoid "fiction." The important thing is to get sound directions to the fellow who is handling the shovel both in the home and in the factory.

NORMAN G. REINICKER agreed with all that had been said about operation, but considered that the biggest gain was not in operation

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but in design. Given a plant and the conditions to operate under, the results were probably 85 per cent due to design and 15 per cent to operation. He thought it was unfortunate that we should have reached the stage of having to save coal now, when we might have saved it a long time ago when plants were originally built, or as they were remodeled, by putting in the proper apparatus.

In designing or remodeling a plant we should take into our confidence the manufacturers of the apparatus. They could give very valuable suggestions.

Improvement in designing did not refer alone to coal saving, but also to labor saving. If, for instance, we could build an ashpit that would hold 24 hours' ashes instead of holding only one dump and requiring a man to be on duty during the whole of the 24 hours to handle the ashes, we could save considerable labor.

Even at the present time we could make our biggest saving, possibly, by changing the apparatus — scrapping some of the old stuff. It was a bad time to do it, of course, because the manufacturers were loaded down with other orders, but we should try to slip in some of these orders for new apparatus from time to time.

WALDRON C. BEEKLEY emphasized the great opportunity for the use of exhaust steam in process water heating as a means of fuel conservation. By putting in apparatus to properly use exhaust steam in heating water for various processes, the coal consumption could be reduced 30 per cent in many cases, particularly in the textile industries.

He noticed in Mr. Myers's paper a suggestion that the Society present some recommendations to the Government in regard to the way in which this fuel problem could be met, and he thought it would be very desirable if the point about which he had just spoken could be followed up.

J. S. LANE. The author's statement "It is evident that we now require an extension of the idea of education, but in such form as directly to affect the men who run the boiler plants of our country, for in their hands is the saving or wasting of one-fourth of the fuel which they consume," is made just as though these men had the matter all in their hands; and, while it is true they do have a good deal in their hands, yet Mr. Cary hit the nail on the head in wanting the right furnaces and the right apparatus. Even though you teach the average fireman the best ways of firing, when your back is turned he will go back to his old way.

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Many boiler plants both small and large, hand-fired or equipped with stokers, are now fitted with appliances that automatically and continuously maintain balanced-draft conditions in the furnace, supplying just the right amount of air required for combustion, maintaining a uniform steam pressure, and allowing the hot gases the longest possible contact with the heating surfaces of the boiler; and a further elimination of the human element can be effected by the use of a mechanical stoker, automatically controlled by a balanced-draft regulator so that the feed of fuel is varied in proportion to the supply of air.

The author also speaks of the railroads, saying, "We are now threatened with a serious coal shortage due chiefly to the overstrained carrying capacity of the railroads." It is believed, however, that if the known methods of saving fuel are employed, thus relieving the railroads from carrying some of it and leaving the saved part in the ground for the use of those who are to come afterward instead of burning it all up now, railroads, coal users, and the general public will be benefited.

EDWARD N. TRUMP. There is one way of reaching the man who shovels the coal into the furnace which has not been touched upon. You should make it to his interest to save the coal.

Many of the old-fashioned plants were satisfied with an efficiency of 50 per cent, which was considered a fair result. I have found it possible to increase that efficiency to nearly 85 per cent, and a large part of that increase was made by making it to the interest of the men who do the work to produce the results.

If you give a bonus to the fireman you will be sure to have some improvement in efficiency. I have found at least 10 per cent saving by paying bonus to the firemen, sometimes by working one shift against the other. Competition encourages them to work harder, to increase the saving.

The installing of such a plan has not proved difficult. If you have the necessary instruments you can in the first place determine the amount of carbonic acid in the waste gases; you can measure the water, take samples of the ashes and determine the amount of carbon, and at the end of the month determine from the weight of coal and the amount of water evaporated the efficiency of the plant.

If you make the shifts compete against each other, and divide a portion of the profit with the shift which gets the best results, you will be surprised at the saving which can be made without any

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changes whatever in the plant. You should save in many cases at least 10 per cent of the fuel.

It is first necessary that careful standards be established by keeping records for a considerable period before the proposition is broached to the men. If a careful record is kept of repairs a standard rate per ton of coal burned can be set. In many cases the saving as determined by the value of the coal can be calculated from the efficiency, and this saving should be divided into three parts: one-third to be set aside for the extra cost of keeping records and for interest and depreciation on measuring and recording apparatus, and the other two-thirds to be divided between the company and the men.

Each man's portion is determined by ascertaining the percentage which the saving bears to the total wages, and each man's earnings are multiplied by the percentage thus obtained to ascertain his bonus. No bonus is given if the standard is not obtained.

The figures as to comparative efficiency and cost of repairs should be published on the bulletin board in the boiler plant every month. By combining the efficiency of the plant with the cost of repairs the tendency to increase repairs to gain efficiency is counteracted.

It is necessary to explain the system very carefully to the men, and to issue instructions which will help them to make a saving and thus earn the bonus.

Having once set the standard it should not be changed unless some change is made in the plant, and this change should be carefully discussed with the men beforehand so that they will agree that the change is fair.

A boiler plant with water-tube boilers of 300-hp. units and with an equipment of economizers of half the surface of the boilers, should give under loads of 100 to 120 per cent of rating an efficiency of 85 per cent, including boilers and stokers. The economizers would give about 7 per cent of this efficiency.

A boiler plant with much larger units, running at the same rating, should give, under good conditions, an efficiency of 88 or even up to 90 per cent.

EDWARD A. UEHLING said that no matter how correct the design of a plant might be, if the fireman did not fire properly the best results would not be obtained. Combustion was a chemical phenomenon and could be diagnosed and controlled only by chemical

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means. This called for apparatus, and it should be of such a nature that the fireman could tell from it instantly the condition of his fire. This, in addition to some of the other things that had been suggested during the discussion, were necessary to bring the maximum efficiency.

WILLIAM B. JACKSON. There is another phase of this situation, namely, that we are endeavoring to work out a plan by which concrete, nation-wide propaganda can be made effective when taking into account many thousands of power plants and not only a relatively few. Furthermore, we have an extremely complicated situation at the present day, in that the personnel of our fireroom forces is in a condition of ferment — our manufacturers do not know today how many of the men who are in their plants will be with them tomorrow; and there is no way for them to estimate how many of their trained firemen, and those who know their equipment, will be with them two or three months hence. Consequently, we have some added critical and difficult aspects of the subject, but that is no reason why the Society should not do everything in its power to work out the best that can be done in this matter. I believe that with effective coöperation we ought to be able to do everything Mr. Myers has suggested, and possibly do a shade better.

THE AUTHOR. I am surprised that some of the discussers do not understand the relation between equipment and operation in their effect upon efficiency. There is a mathematical equation which expresses this relation, which is as follows: Efficiency in any process is equal to the efficiency of the mechanical equipment multiplied by the efficiency of the human factor. This may be expressed: Efficiency equals $E \times H$. For example, in the matter of fuel economy, if we have a furnace perfectly designed and adapted for a specified fuel and purpose, we may regard our equipment as having an efficiency of 100 per cent, but if the man who operates the furnace is drunk, the efficiency of the operation will be zero.

Take it the other way around, and suppose we have a perfect fireman but the grate has fallen out of the furnace; our efficiency will again be zero. Thus, as stated, the formula $E \times H$ truly expresses the relation between equipment and operation in determining the efficiency of any process.

Consequently, we must of course endeavor to obtain the highest attainable efficiency both of equipment and of operation in order to realize the maximum of combined or ultimate efficiency.

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The point of all this is that by improving the efficiency of operation alone, the combined efficiency is susceptible of great and immediate improvement. Without loss of time and without expenditure for new or changed equipment, an average saving of 10 to 20 per cent of coal can be effected in factory boiler plants. Therefore, in a fuel-saving campaign adequate measures must be directed first toward obtaining the maximum improvement possible in the way of purely operating economies. Later, the equipment side of the proposition should be given urgent attention.

The immediate problem before us is to develop ways and means for putting into effect these economies which I have shown may equal 50 million to 100 million tons of coal saved per year. These savings may go into effect at once.

I regret that the greatest volume of discussion on my paper has been directed toward technicalities. All competent engineers who have studied the fuel problem know the technical side of the situation, and if I had been allowed the time and space I could have presented all of the technical information and suggestions which have been involved in this discussion. All good fuel engineers know these things; the bad ones do not count.

The present situation does not call for technical discussion but it does call for *ways and means* for putting into effect the knowledge which we now have, and in such a manner as to save the 50 million to 100 million tons of coal per year which can be saved. A few very interesting suggestions on ways and means have been brought forward in the discussion.

Let me first state most emphatically that education will comprise an essential feature in the campaign for saving coal which will be adopted and successfully prosecuted in this country: education of the owner, education of the firemen.

Incentive must be added to education so that manufacturers and owners will *desire* to coöperate in the fuel-saving campaign. It is probable that for the most part patriotism and efficiency will provide sufficient incentive, but to this may be added the shutting down of inefficient plants in case of necessity. It would not be fair to the highly efficient plants to cut off their coal supply while wasteful plants were literally throwing away coal. The whole question resolves itself into that of ways and means for executing the measures of economy which all fuel engineers know are necessary at this time. It is desirable to work as far as possible through existing agencies and organizations. For instance, the federal, state and local chambers of commerce are

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already working along these lines to some extent and they should be encouraged and helped from headquarters by bulletins on fuel economy, the furnishing of lecturers, starting of schools for firemen, etc. Then the manufacturers' associations will be of very great value. They should be urged to pledge themselves to a campaign of fuel economy in their respective localities. They should get together for meetings devoted to the subject; they should obtain the best fuel engineers in their vicinity to lecture to them; they should get the services of these men to visit their plants and make suggestions and adopt further sensible plans for saving fuel.

Any plant owner who failed actively to install methods for economizing in the use of fuel in his plant would be considered a bad citizen by the other members of his association who would be working for governmental interests. This bad citizen would be made to feel the displeasure of his neighbors and would probably take heed and give attention to his own plant. If this did not work, then the Government could compel him to bring his plant up to a suitable degree of efficiency or limit his coal supply.

Mr. Podolsky in his discussion made a suggestion along these general lines when he spoke of a national society for fuel saving. The local manufacturers' association to which I have alluded, could, if found desirable, be combined to form such a national society or association. This constitutes one of the most valuable suggestions that has been made in the discussion.

While our problem relates principally to fuel saving, labor saving is also important. Mr. Reinicker has brought out this feature in a limited way in his suggestion regarding an ashpit to hold 24 hours' accumulation. Of course this phase of the subject could be developed indefinitely, but this is aside from the present object. Mr. Reinicker, however, is wrong in his statement that "the results are probably 85 per cent due to design and 15 per cent to operation." As I demonstrated in the first part of my discussion, the combined efficiency is equal to the efficiency of the equipment multiplied by the efficiency of operation, and in my own practice I have found that in most factory plants a saving of 10 to 25 per cent can be made by modification of operating methods alone. I can quote cases where improvement has been as high as 50 per cent. Further savings, depending upon the original design of the plant, can be made by suitable changes in the equipment.

Mr. Beekley brings out the fact that there is a large saving to be made by the utilization of exhaust steam. This point was brought

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out in my paper in Par. 23. The actual saving, however, in case all the exhaust from an ordinary factory engine is utilized would approximate 90 per cent instead of the 30 per cent which Mr. Beekley quotes. (See my paper entitled The Heating Value of Exhaust Steam, presented at the annual meeting of the American Society of Heating and Ventilating Engineers in January 1915, in which I gave a formula for determining the heat value of exhaust steam from any engine, pump or turbine. In this paper are given curves from which the heat value of exhaust is determined graphically.)

Mr. Trump's discussion is extremely valuable as he is bringing out the new idea in boiler-room management of giving the firemen an interest in the coal which they are able to save by intelligent effort. The statement which he has made should be convincing since it is based on actual experience in his own large plants. I have designed bonus systems for many plants in this country. The reason that many bonus systems have failed is that they have not been suited to the particular case and local conditions for which they are supposed to be designed. But the bonus system will be increasingly used in this country during the coming years in connection with boiler-house accounting systems. Every plant in the country which burns as much as five tons of coal per day should have some kind of an accounting system to indicate at least approximately the efficiency of the boilers and furnaces. The best system is continuous weighing of coal and water by modern methods supplemented by flue-gas analysis. But where this complete system cannot be installed for practical reasons, a flue-gas-analysis system can be and should be installed. The United States Fuel Administration should endorse this specific measure in formulating a program to be sent out through the State Fuel Administrators to the industries.

Mr. Polakov speaks slightingly of what he is pleased to term "by correspondence-school methods." I did not suggest correspondence-school methods but I did suggest education by every possible means, both by personal teaching and by bulletins and circulars prepared specifically for definite purposes. Mr. Polakov's method is quite suitable for private consulting practice such as his or mine, and I follow his thorough methods in my own practice. But Mr. Polakov has evidently not considered the difference between a private practice and a national practice. For instance, were we to carry out Mr. Polakov's idea it would require four thousand Mr. Polakovs working eighteen months at a cost to the Government of $36,000,000 to make an inspection of three or four days in each industrial plant in the

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country. In the first place, we have not got four thousand Polakovs, neither can we wait eighteen months, and $36,000,000 is too much to pay for it. His plan is impracticable when it comes to a large-scale proposition.

What we require at the present time is a constructive policy and program which must be taken up by the United States Fuel Administration in a comprehensive manner. The plan must involve all the elements which I have suggested and there is no doubt but what such a plan will be formulated and adopted with large results. The 50,000,000 to 100,000,000 tons of coal a year can be saved and must be saved.

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No. 1611

THE TRANSFER OF HEAT BETWEEN A FLOWING GAS AND A CONTAINING FLUE

By Lawford H. Fry, Burnham, Pa.
Member of the Society

The work on which the paper is based began as a study of the locomotive boiler, the object sought being a practical working formula for determining the drop of temperature between firebox and smokebox. The experiments studied covered, however, a wider range of conditions, and the final formula is of more general application. It applies equally well to the cooling of products of combustion from high temperatures, and to the warming of gases at atmospheric temperatures. It can be used with confidence with flues of circular or of annular section up to 2 in. in diameter and can probably be applied to larger flues of irregular section such as the gas passages in a water-tube boiler.

The general formula is most simply expressed as follows: If a gas flow x ft. through a flue of which the mean wall temperature is t, the change in temperature of gas from T_1 to T_2 is given by the expression

$$\text{lolog } T_1/t - \text{lolog } T_2/t = Mx$$

when the gas is hotter than the flue, or by the expression

$$\text{lolog } t/T_1 - \text{lolog } t/T_2 = Mx$$

when the flue is hotter than the gas. In either case "lolog" means "the logarithm of the logarithm" and M is a coefficient dependent on the flue dimensions and on the rate of flow of gas. The three temperatures T_1, T_2, and t are to be measured from the absolute zero in any scale. If the gas flow at the rate of W lb. per hour, and if p be the perimeter of the flue in inches, the coefficient M has the form given by the equation

$$\log M = B - m \log W/p$$

In flues of irregular section the perimeter p is found by dividing the heat-transfer surface in contact with the gas by the length of travel of gas, all dimensions being in inches.

The coefficients B and m depend on the mean hydraulic depth of the flue. For convenience in dealing with flues of circular section, which are those most usually met with, the diameter (which in a circular flue is four times the hydraulic depth) is used below instead of the hydraulic depth. The relation between the flue diameter

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Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers.

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d and the coefficients B and m is given by the lines in Fig. 23. The equations to these lines are:

$$\log (B - 1.3) = \bar{1}.71 - 0.54 \log d$$
$$\log m = \bar{1}.36 - 0.37 \log d$$

For flues of sections other than circular the value of d is found by multiplying the mean hydraulic depth by four. Mean hydraulic depth is equal to area of cross-section divided by perimeter.

The equations given for B and m in the paper give accurate results for flues up to 2 in. in inside diameter, but those shown above can be applied to larger flues.

THE transfer of heat between a flowing gas and the wall of a metallic flue through which the gas flows is one of the most important processes in mechanical engineering, and as such has been the subject of much study by physicists and by engineers. All attempts, however, to bring the process under the yoke of a general formula have been very imperfectly successful.

2 The author now offers the formula described below, which within a wide range of conditions will represent with all the accuracy needed for practical work the processes of heat transfer between a gas and a metallic flue wall.

3 The formula applies equally well to the loss of heat by a hot gas in a cooler flue and to the gain of heat by a cool gas in a hotter flue, and although it has been established by purely empiric methods, yet the accuracy with which it conforms to the results obtained by various observers using widely differing experimental methods leads to the belief that it represents closely the fundamental law by which heat is transferred under the conditions considered.

4 The wide range of the experimental data on which the formula is based is shown in Table 1 and may be summarized briefly as follows:

Gases. The gases experimented with were products of combustion, lighting gas, CO_2 and air, all at atmospheric pressure; also air at pressures ranging from 0.15 to 140 lb. per sq. in. abs.

Rate of Flow of Gas. The rates of flow ranged from 0.5 to 650 lb. per hr.

Flues. Flues of annular and circular cross-section were used, with effective diameters ranging from 0.5 to 2.0 in., and of lengths from 0.64 to 20 ft.

Temperatures. The inlet gas temperatures ranged from 2340 deg. fahr. with the products of combustion being cooled, to 55 deg. fahr. with air being warmed.

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TABLE 1 RANGE OF CONDITIONS COVERED BY EXPERIMENTAL DATA

Experimenter and gas used	Number of experiments	Gas: Range of temperatures, deg. fahr. Inlet Min.	Inlet Max.	Outlet Min.	Outlet Max.	Gas: Rate of flow, lb. per hour Min.	Rate of flow, lb. per hour Max.	Flue: Shape of section	Effective inside diam., inches	Length used in experiments, feet Min.	Length used in experiments, feet Max.	Range of mean wall temperatures, deg. fahr. Min.	Range of mean wall temperatures, deg. fahr. Max.	Conditions surrounding gas flue
JORDAN														
Series B Air	15	238	545	147	235	108	550	Annular	(0.684)	3.28		68	106	Surrounded by annular water flue carrying cooling water flowing in direction opposite to that of air flow.
Series C Air	14	357	750	245	373	108	600	Annular	(1.04)	3.28		55	126	
Series D Air	14	319	604	250	443	108	620	Circular	1.968	3.28		55	86	
Series E Air	12	365	637	154	258	30	98	Circular	0.506	3.28		72	130	
Series F Air	17	381	736	260	468	72	520	Circular	1.236	3.28		67	102	
NUSSELT										Min.	Max.			
1. Air at 14 lb./sq. in. abs.	13	78	155	109	187	1.6	108	Circular	0.868	0.89	1.95	217		Surrounded by steam jacket maintained at atmospheric pressure.
2. Same as 1, with long entrance flue	10	55	115	124	176	1.7	100	Circular	0.868	0.96	3.70	217		
3. Air at 140 lb./sq. in. abs.	12	62	115	81	148	16.6	420	Circular	0.868	1.96	1.96	217		
4. CO_2 at 14 lb./sq. in. abs.	10	70	125	108	150	6.4	137	Circular	0.868	1.00	1.96	217		
5. Lighting Gas at 14 lb./sq. in. abs.	12	74	144	124	177	1.0	38	Circular	0.868	0.64	1.96	217		
BABCOCK & WILCOX CO. Products of Combustion	7	1735	2340	377	649	94	313	Circular	2.0	17		160	200	Surrounded by water jackets each one foot long, to which cooling water is applied.
FESSENDEN Products of Combustion														Surrounded in each series by ten jackets to which water is fed and boiled at atmospheric pressure.
Series I	19	1473	1971	414	563	40.0	17.0	Circular	1.816	10.95		212		
Series II	17	1492	2003	247	306	11.8	125.8	Circular	0.816	10.44		212		
JOSSE														Surrounded by steam jacket maintained at atmospheric pressure.
1. Air at 14.7 lb./sq. in. abs.	7	62	70	138	171	5.3	71	Circular	0.905	4.34		212		
2. Air at 7.2 lb./sq. in. abs.	5	67	68	150	186	4.8	34	Circular	0.905	4.34		212		
3. Air at 1.5 lb./sq. in. abs.	5	80	96	162	188	0.5	37	Circular	0.905	4.34		212		
PENNSYLVANIA R. R. Products of Combustion														
Series 600	11	1476	2177	500	689	64	171	Circular	2.00	18.75		390		Experiments with locomotive boilers.
Series 900	17	1774	2266	562	740	121	252	Circular	1.75	15.00		387		

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5 In all of the experiments throughout this wide range of conditions the transfer of heat is satisfactorily represented by the general formula proposed below.

GENERAL FORMULA FOR HEAT TRANSFER

6 The type of formula used is adapted from that suggested by Fessenden and Hedrick.[1] No attempt is made to measure the rate of heat transfer per square foot of heating surface per degree of temperature difference, but an expression is given for the rise or fall in temperature of a gas in its passage along a flue the wall of which is at a higher or a lower temperature than the gas.

7 If a gas flows at the rate of W lb. per hour through a flue of which the hydraulic depth is $d/4$ in. (in a flue of circular section the diameter corresponding to this hydraulic depth is d in.), and if the temperature of the gas be T_1 deg. in any given section and T_2 deg. in a section x ft. distant in the direction of the flow, and if the mean flue temperature between these two sections be t deg., all temperatures being measured from the absolute zero in any scale; then, if the gas temperature be higher than the flue temperature,

$$\text{lolog } T_1/t - \text{lolog } T_2/t = Mx \quad [1]$$

and if the flue temperature be higher than the gas temperature,

$$\text{lolog } t/T_1 - \text{lolog } t/T_2 = Mx \quad [1a]$$

where M is a constant in any given case, being dependent only on W the rate of flow of the gas, on p the perimeter of the flue, and on $d/4$ the hydraulic depth of the flue.[2] In the experiments under consideration there is a critical rate of flow at about 5 lb. of gas per hour in a flue 0.868 in. in diameter. At all rates of flow above this the coefficient M is accurately given by the equations

$$\log M = B - m \log W/p \quad [2]$$

where

$$B = \bar{1}.56 - 0.30\,d \quad [3]$$

and

$$m = 0.14 + 0.083\,d \quad [4]$$

and p is the flue perimeter in contact with the gas measured in inches. In the case of flues of circular section the equation can be simplified

[1] Trans. Am.Soc.M.E., vol. 38, p. 407.

[2] Chappell's very convenient logarithmic notation is used, by which "lolog N" denotes "the logarithm of the logarithm of the number N" all logarithms being to the base 10. (Five Figure Mathematical Tables, by E. Chappell.)

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by omitting the perimeter from separate consideration, since in the circular section both perimeter and hydraulic depth are fixed by the diameter. The equations can then be written

$$\log M = A - m \log W \quad \ldots\ldots\ldots\ldots\ldots\ldots [2a]$$

where

$$A = \bar{1}.58 - 0.185\, d \quad \ldots\ldots\ldots\ldots\ldots\ldots [3a]$$

and m has the value given above in Equation [4].

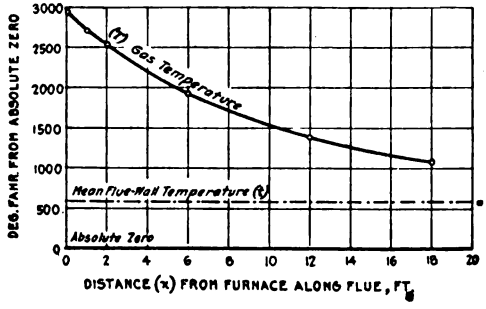

FIG. 1 MEAN GAS TEMPERATURES AND MEAN FLUE TEMPERATURE
(B & W Test 1, April 13.)

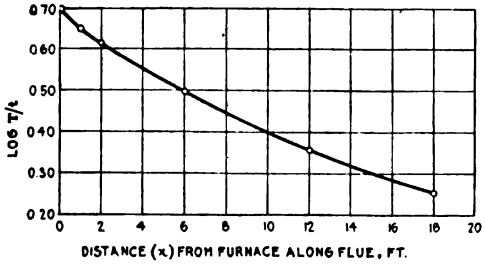

FIG. 2 LOGARITHM OF RATIO OF GAS TEMPERATURE TO FLUE TEMPERATURE
(B & W Test 1, April 13.)

8 The application of Equation [1] is illustrated by Figs. 1, 2 and 3, which are based on one of the Babcock and Wilcox experiments in which products of combustion at a high temperature were passed through a water-jacketed flue and the temperature determined at a number of points along the flue. The abscissæ in all three figures are distances in feet from the furnace end of the flue. In Fig. 1 the ordinates of the curve are the gas temperatures T in degrees fahrenheit above the absolute zero. A horizontal line is also drawn having as ordinates the mean flue-wall temperature t.

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9 In Fig. 2 the ordinates are the logarithms of the ratio of gas temperature to mean flue temperature, log T/t, while in Fig. 3 the ordinates are the logarithms of the ordinates in Fig. 2, that is, they are the logarithms of the logarithms of the temperature ratios, [log (log T/t) or lolog T/t]. In Fig. 3 the points plotted fall on a straight line and it is obvious that if T_1 be the gas temperature at any point and T_2 the gas temperature at a point x ft. further along the flue the relation between the two temperatures is given by the equation

$$\text{lolog } T_1/t - \text{lolog } T_2/t = Mx \quad \ldots\ldots\ldots\ldots\ldots [1]$$

where M is the slope of the line.

10 The purpose of the present paper is (1) to show that this relation is a general one, and (2) to show how M, the coefficient measuring the slope of the lolog line, is affected by the rate of flow of

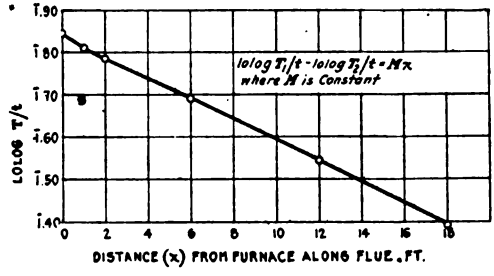

FIG. 3 LOGARITHM OF LOGARITHM OF TEMPERATURE RATIO
(B & W Test 1, April 13.)

the gas and by the flue diameter. It should be noted that the coefficient M is dependent not on the actual diameter of the flue but on the hydraulic depth, that is, on the quotient of the area divided by the perimeter. In the case of a flue of circular cross-section the hydraulic depth is one-quarter the diameter, and it is immaterial whether diameter or hydraulic depth be taken as argument in establishing the relationship with the coefficient M. As most of the present work concerns circular flues, it is convenient to use the "effective diameter" d in determining the relation between flue section and the coefficient M. This effective diameter, being defined as four times the hydraulic depth, is the same as the actual diameter in a flue of circular cross-section. Examination of the experimental data has led to the conclusion that the relation between the coefficient M, the rate of flow of gas W, and the effective flue diameter d, is that shown above in Equations [2], [3] and [4].

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EXPERIMENTAL DATA

11 The data on which the conclusions stated above are based have been derived from a total of 205 experiments, the range of conditions covered by them being shown in Table 1. These experiments fall into six groups, each of which is due to a different experimenter. The Jordan[1] experiments are among the most accurate, and as they cover the widest range of flue diameters, have played a considerable part in establishing the formulæ. They comprise five series, each with a flue of a different section. Two of the flues were annular and three circular in section, the effective diameter ranging from 0.506 to 1.968 in. The gas used was air, the rate of flow ranging from 30 to 620 lb. per hr. and the inlet temperature from 238 to 750 deg. fahr. The air was passed through a vertical flue 3.28 ft. long, surrounded by cooling water flowing in the opposite direction to the air. Inlet and outlet temperatures of the air were measured.

12 The Nusselt[2] experiments were made with air at a pressure of 140 lb. per sq. in. abs., and with air, CO_2 and lighting gas at atmospheric pressure. These gases at atmospheric temperatures were passed through a horizontal flue 0.868 in. in diameter surrounded by steam at atmospheric pressure, and the rise in temperature measured. The length of flue in which the temperature rise took place varied from 0.64 to 1.96 ft. The rate of flow of gas varied from 1 to 400 lb. per hr. These experiments were carried out with great care and are valuable on account of the wide range of rate of gas flow, and because gases of various compositions were used.

13 The Josse[3] experiments, like those of Nusselt, were made with a horizontal steam-jacketed flue, through which air at atmospheric temperature was passed and the rise in temperature measured. Pressures of 1.5, 7.5 and 15 lb. per sq. in. were used, the rate of flow ranging from 0.5 to 71 lb. per hr. The flue was 0.905 in. in diameter and 4.34 ft. long.

14 The Babcock and Wilcox[4] experiments considered here are seven in number, taken at random from an elaborate series in which

[1] Proc. Inst. M. E., 1909, p. 1317.

[2] Mitteilungen über Forschungsarbeiten, vol. 89 (1910).

[3] Zeitschrift des Vereines deutscher Ingenieure, 1909, p. 322.

[4] Experiments on the Rate of Heat Transfer from a Hot Gas to a Cooler Metallic Surface. The Babcock & Wilcox Co., 1916. (The data of one experiment are published in this book, while those for the other six used in this paper were furnished to the author by the Babcock & Wilcox Co. through the courtesy of Mr. Arthur D. Pratt.)

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the products of combustion from a gas furnace were passed through a water-jacketed flue 2 in. in diameter and 20 ft. long. The gas inlet temperatures ranged from 1750 to 2350 deg. fahr., and as the water jacket was divided into twenty compartments each one foot long, the drop in temperature of the gas along the flue could be determined by measuring the amount of heat absorbed in each compartment of the jacket. The mean water temperature was approximately 160 deg. fahr.

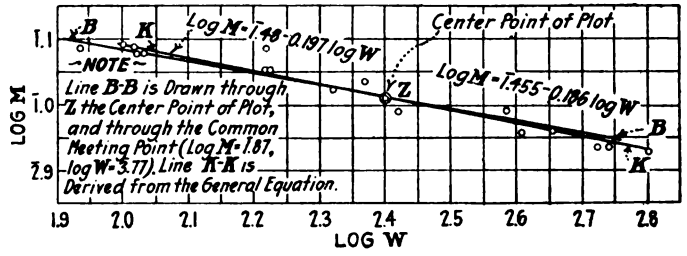

FIG. 4 RELATION BETWEEN COEFFICIENT *M* AND RATE OF AIR FLOW (*W*) FROM JORDAN'S EXPERIMENTS, SERIES B

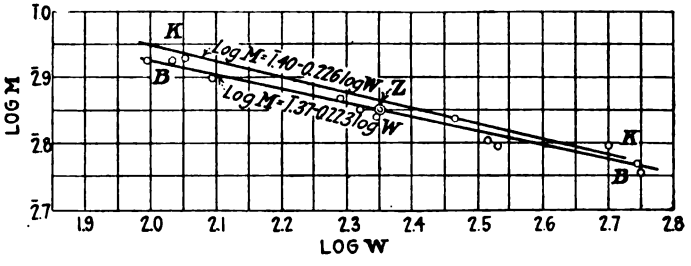

FIG. 5 RELATION BETWEEN COEFFICIENT *M* AND RATE OF AIR FLOW (*W*) FROM JORDAN'S EXPERIMENTS, SERIES C

(See note on Fig. 4)

15 The Fessenden[1] experiments were very similar to the Babcock and Wilcox, but in one series a flue 1.816 in. in diameter and 10.95 ft. long, and in the other series a flue 0.816 in. in diameter and 10.44 ft. long, was used. In both series the jacket was divided into ten compartments in which water was allowed to boil at atmospheric pressure. Inlet and outlet temperatures were measured, and the drop of temperature along the flue could be found by measuring the amount of heat given up to each compartment of the jacket.

[1] University of Missouri Bulletin, vol. 17, no. 26 (October 1916).

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16 The Pennsylvania Railroad[1] experiments are taken from tests of locomotives on the Altoona locomotive testing plant. One boiler had flues 2 in. in diameter and 18.75 ft. long, the other had flues 1.75 in. in diameter and 15 ft. long. The firebox and smokebox temperatures were measured in each experiment and the weight of the products of combustion determined from the flue-gas analysis.

DERIVATION OF FORMULÆ FROM EXPERIMENTAL DATA

17 The process of studying the validity of Equation [1] and of arriving at the law expressed by Equations [2], [3] and]4] is illustrated by Figs. 4 to 13.

18 The first step was to calculate from the figures obtained experimentally the value of the coefficient M in Equation [1]. This having been done and the results tabulated, it became evident that in each series of experiments made with the same diameter of flue the values of M decreased regularly as the rate of gas flow increased. In the search for the law governing this change the values of $\log M$ were plotted as ordinates over the values of $\log W$ as abscissæ, (W = lb. of gas per hr.). Fig. 11 showing the results obtained from Nusselt's experiments is typical and is of interest as covering the widest range of gas-flow rates and as covering gases of three different compositions and of widely different pressures. From this plot it appears that there is a critical rate of flow at about 5 lb. of gas per hr., $W = 5$, $\log W = 0.699$, and that for rates of flow greater than this the relation between $\log M$ and $\log W$ is a well-marked straight line of the form $\log M = A - m \log W$ (Eq. [2]).

19 Before examining the numerical values of the coefficients in this equation, attention will be directed to the meaning of the two formulæ which have been set up. In Fig. 12, which is Fig. 11 redrawn in diagram form, AB represents the lolog of the temperature ratio at a given cross-section of the flue and CD the lolog of the temperature ratio at a section x ft. further along the flue. Then the slope of the line AC is determined by the value of the coefficient M. If the coefficient has a larger value, say M', the line will have a sharper slope and the value of lolog t/T_2 will be CD, which is less than before. This means that the temperature T_2 will be greater than before. An increase in the value of the coefficient M corresponds to a more rapid

[1] Locomotive Tests and Exhibits, The Pennsylvania R. R. System, 1905. Tests of an E2A Locomotive, Locomotive Testing Plant Bulletin No. 5, Pennsylvania R. R. Co., 1910.

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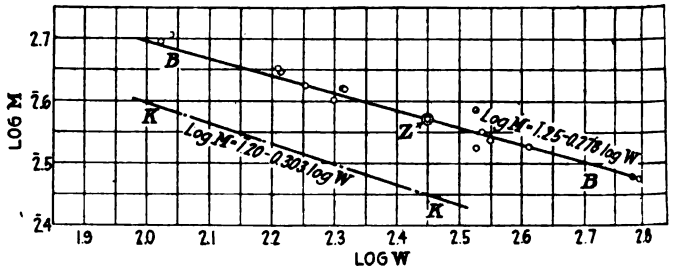

FIG. 6 RELATION BETWEEN COEFFICIENT M AND RATE OF AIR FLOW (W) FROM JORDAN'S EXPERIMENTS, SERIES D

(See note on Fig. 4)

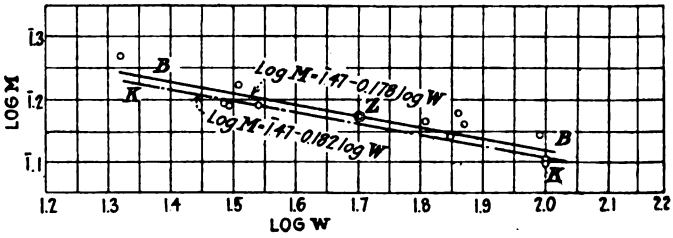

FIG. 7 RELATION BETWEEN COEFFICIENT M AND RATE OF AIR FLOW (W) FROM JORDAN'S EXPERIMENTS, SERIES E

(See note on Fig. 4)

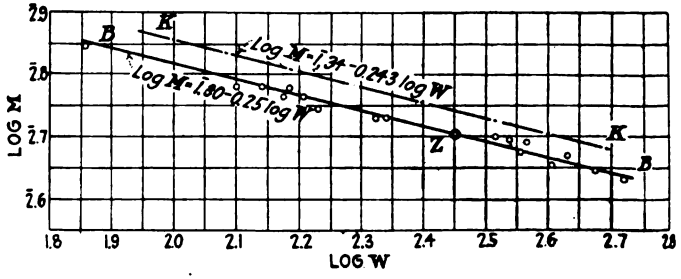

FIG. 8 RELATION BETWEEN COEFFICIENT M AND RATE OF AIR FLOW (W) FROM JORDAN'S EXPERIMENTS, SERIES F

(See note on Fig. 4)

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interchange of heat between flue wall and gas, and consequently, in the case under consideration, to a greater increase in the temperature of the gas.

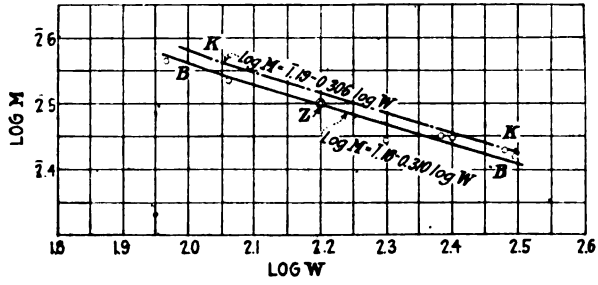

FIG. 9 RELATION BETWEEN COEFFICIENT M AND RATE OF GAS FLOW (W) FROM THE BABCOCK AND WILCOX EXPERIMENTS

(See note on Fig. 4)

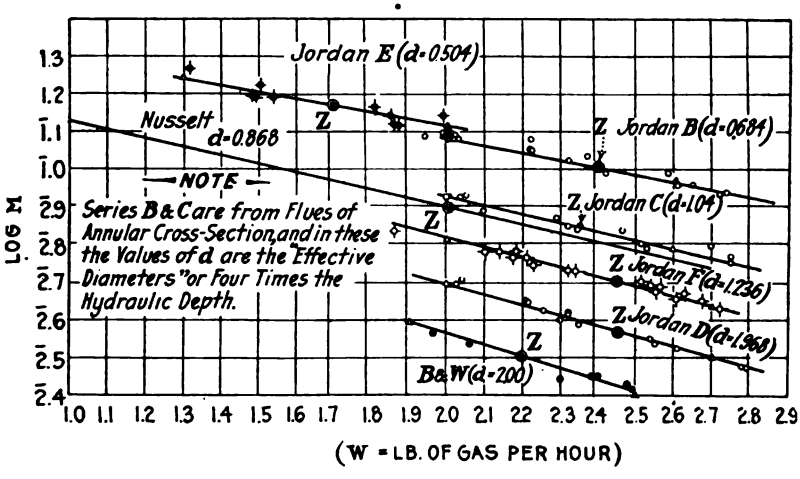

FIG. 10 RELATION BETWEEN COEFFICIENT M AND RATE OF FLOW OF GAS FOR VARIOUS FLUE DIAMETERS

All lines are represented by the equation

$$\log M = \bar{1}.87 - (2.23 + \log W)\, m,$$

which may be written $\log M = A - m \log W$, where $A = \bar{1}.87 - 2.23\, m$. This indicates that all of the lines if extended will pass through the point at which $\log M = \bar{1}.87$ and $\log W = -2.23 = \bar{3}.77$.

20 The influence of the rate of gas flow on the coefficient M in any given flue is well illustrated by Fig. 11. As the rate of flow is increased the value of the coefficient M decreases, that is to say, the amount of change in the temperature of the gas between any two

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points decreases. For example, in Fig. 11 the line drawn through the plotted points of the Nusselt experiments shows the following values for log W and log M:

log W =	1.0	1.505	2.00	2.70
log M =	$\bar{1}$.123	$\bar{1}$.017	$\bar{2}$.905	$\bar{2}$.755

from which the following values are found for W and M:

W =	10	32	100	500
M =	0.1328	0.1040	0.08036	0.05689

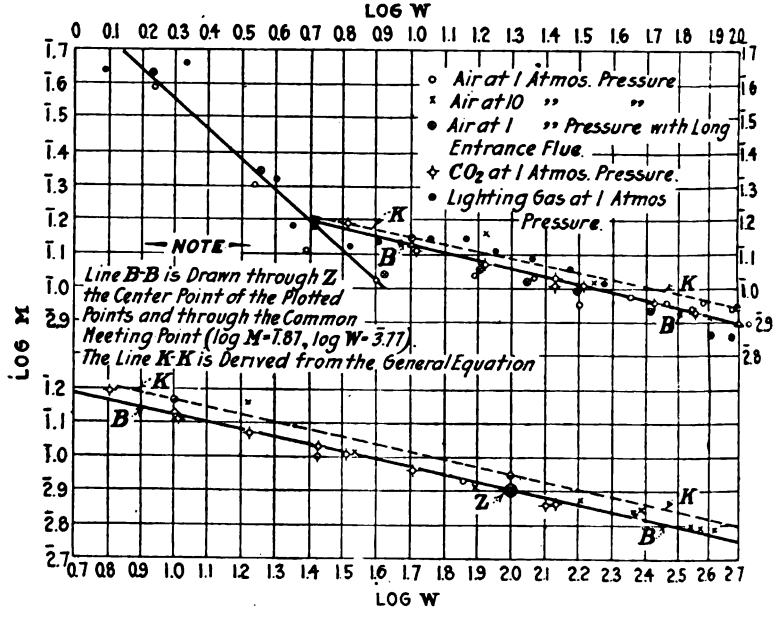

FIG. 11 RELATION BETWEEN COEFFICIENT M AND RATE OF GAS FLOW FROM NUSSELT'S EXPERIMENTS WITH VARIOUS GASES

21 If an initial gas temperature of 70 deg. fahr. be assumed, the temperature of the gas after passing 1 ft. along the flue which is maintained at 212 deg. fahr. will vary as follows:

Rate of flow, lb. per hr.,	W = 10	32	100	500
Temperature, deg. fahr.,	T_2 = 105.5	98.5	92.5	86.0
Rise in temperature,	$T_2 - T_1$ = 35.5	28.5	22.5	16.0

22 The rise in temperature becomes less and less as the rate of flow is increased. If the amount of heat transferred to the gas is calculated from the foregoing, assuming a specific heat of 0.238, the following figures are obtained:

Rate of flow, lb. per hr.....	W = 10	32	100	500
Heat transfer, B.t.u. per hr., 0.238 W ($T_2 - T_1$) =	84.6	217	536	1910

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23 From this it will be seen that when flowing at the rate of 10 lb. per hr. the temperature of the gas is raised 35.5 deg. out of a

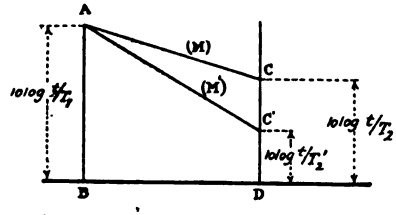

FIG. 12 DIAGRAM SHOWING EFFECT OF A CHANGE IN THE VALUE OF THE COEFFICIENT M

possible 42 deg., the transfer of heat being at the rate of 84.6 B.t.u. per hr., while if the rate of flow is increased to 500 lb. per hr. the tem-

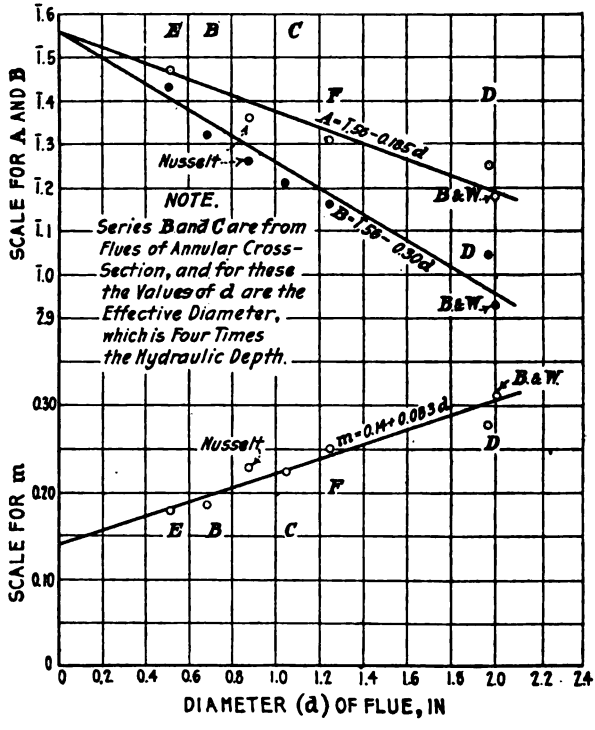

FIG. 13 RELATION BETWEEN FLUE DIAMETER (HYDRAULIC DEPTH) AND COEFFICIENTS A, B AND m IN THE EQUATIONS LOG $M = A - m$ LOG W AND LOG $M = B - m$ LOG W/p

perature rise is only 16 deg., but the heat is transferred at the rate of 1910 B.t.u. per hr.

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24 By increasing the rate of flow of the gas the efficiency of the heat transfer, that is, the ratio of heat transferred to heat which might be transferred, is reduced; but the effectiveness of the transfer surface, that is, the amount of heat transferred per hour in a given length of flue, is increased very considerably.

NUMERICAL VALUES FOR COEFFICIENTS

25 Returning to Equations [1] and [2] to evaluate the coefficients, Figs. 4 to 14 come under observation. In carrying out this evaluation it was recognized that the slope of the line expressing the relation between log M and the rate of flow of the gas, that is, the coefficient m, is the same whether values of log W or of log (W/p) be taken as abscissæ. The values of log M were therefore plotted against the values of log W as shown. This having been done for the five Jordan series, for the Nusselt and for the Babcock and Wilcox groups of experiments, all of which can lay claim to a high degree of accuracy, it became evident that, as indicated by Equation [4], the value of m varied with the hydraulic depth of the flue. This is made clear by Fig. 10, in which the seven series just referred to are brought together in one plot. It was also evident that the values of the coefficients A or B were also functions of the hydraulic depth. The problem then narrowed down to the selection of values for these coefficients which should be in some regular relation to the effective flue diameter, and which should at the same time harmonize with the individual points derived from the experiments.

26 In studying this problem it was found that in each series of experiments the points plotted in Fig. 10 could be closely represented by a group of straight lines and all the lines thus obtained passed through the point ($\log M = \bar{1}.87$, $\log W = \bar{3}.87$). In other words, the points representing the relation between log M and log W for all the experiments in the seven series now under consideration lie on a series of straight lines radiating from the common point ($\log M = \bar{1}.87$, $\log W = \bar{3}.77$). Having discovered this property, the positions of the lines shown in Fig. 10 were established by choosing for each series of experiments a center point (these are the points marked Z in Fig. 10) and drawing lines through the common meeting point and through these center points.

27 Table 2 shows in columns 3 and 4 the coördinates of the center points selected for each series, and in columns 5 and 6 the values of the coefficients A and m for each of the lines passing through these center points and through the common meeting point. To con-

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nect the coefficient m with the effective flue diameter the values from column 6, Table 2, were plotted as ordinates in Fig. 13 over the flue diameters d as abscissæ. All of the points lie fairly close to a straight line, and for the coefficient m a line with the equation $m = 0.14 + 0.083\,d$, or Equation [4], was chosen as representing most satisfactorily the relation between m and d. It will be understood that the choice of the center points Z and the lines drawn through these and the common meeting point are merely steps leading to the tentative values of m which are plotted in Fig. 13. These lead to the final harmonized values given by Equation [4], which represents the line for m in Fig. 13. These values for each of the series are given in column 9, Table 2. Smoothed values of the coefficient A for the five series of tests with the flues of circular section were found by the following consideration: Since all the lines in Fig. 4 pass through the point ($\log M = \bar{1}.87$, $\log W = \bar{3}.77$), they can all be represented by the equation

$$\log M = \bar{1}.87 - (\log W - \bar{3}.77)\, m \quad \ldots\ldots\ldots\ldots [5]$$

which can be written,

$$\log M = \bar{1}.87 - (2.23 + \log W)\, m \quad \ldots\ldots\ldots\ldots [5a]$$

since $3.77 = -2.23$, or by regrouping,

$$\log M = (\bar{1}.87 - 2.23\, m) - m \log W \quad \ldots\ldots\ldots\ldots [5b]$$

Combining this with Equation [2], it follows that

$$A = \bar{1}.87 - 2.23\, m \quad \ldots\ldots\ldots\ldots\ldots\ldots [6]$$

and giving m the value found above in Equation [4], Equation [6] becomes

$$A = \bar{1}.56 - 0.185\, d \quad \ldots\ldots\ldots\ldots\ldots\ldots [3]$$

The line having this equation and the tentative values of A from column 5, Table 2, are plotted in Fig. 13. To find the relation between B and d as expressed in Equation [3], Equations [2] and [2a] are compared. From Equation [2] it follows that

$$\log M = B + m \log p - m \log W$$

and comparing this with Equation [2a], it follows that

$$B = A - m \log p$$

from this relation and knowing the perimeters of the various flues, tentative values of B were computed from the tentative values of A in column 5, Table 2. The results are shown in column 7 of Table 2

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TABLE 2 VALUES OF COEFFICIENTS A AND m USED IN DRAWING B-B AND K-K LINES IN FIGS 4 TO 17

Experiments	Flue diameter, inches	Coördinates of point chosen as center of plotted points		Value of coefficients A and m found for line drawn through the center point and through the common meeting point having coördinates Log $M=\bar{1}.87$, Log $W=\bar{3}.77$		Tentative values of coefficient B found from cols. 5 and 6 by the equation $B=A-m \log p$	Values of coefficients corresponding to the flue diameter d, as given by the straight lines in Fig. 13 $A=\bar{1}.56-0.185\,d$ $m=0.14+0.063\,d$	
(1)	(2) d	(3) Log M	(4) Log W	(5) A	(6) m	(7) B	(8) A	(9) m
Babcock & Wilcox	2.00	$\bar{2}.500$	2.20	$\bar{1}.18$	0.310	$\bar{2}.93$	$\bar{1}.19$	0.306
Jordan, Series B[1]	(0.684)	$\bar{1}.010$	2.40	$\bar{1}.455$	0.186	$\bar{1}.32$	$\bar{1}.43$	0.197
Jordan, Series C[1]	(1.04)	$\bar{2}.850$	2.35	$\bar{1}.37$	0.223	$\bar{1}.21$	$\bar{1}.37$	0.226
Jordan, Series D	1.968	$\bar{2}.570$	2.45	$\bar{1}.25$	0.278	$\bar{1}.05$	$\bar{1}.20$	0.303
Jordan, Series E	0.506	$\bar{1}.170$	1.70	$\bar{1}.47$	1.178	$\bar{1}.43$	$\bar{1}.47$	0.182
Jordan, Series F	1.236	$\bar{2}.705$	2.45	$\bar{1}.31$	0.250	$\bar{1}.16$	$\bar{1}.34$	0.243
Nusselt	0.868	$\bar{2}.905$	2.00	$\bar{1}.36$	0.228	$\bar{1}.26$	$\bar{1}.40$	0.212
Fessenden, Series I	1.816	.....	.....	.....	.....	.....	$\bar{1}.23$	0.291
Fessenden, Series II	0.816	.....	.....	.....	.....	.....	$\bar{1}.41$	0.208
Josse	0.905	.....	.....	.....	.....	.....	$\bar{1}.39$	0.216
Penna. R. R., Series 600	2.00	.....	.....	.....	.....	.....	$\bar{1}.19$	0.306
Penna. R. R., Series 900	1.75	.....	.....	.....	.....	.....	$\bar{1}.25$	0.285

[1] The flues in the Jordan series B and C have annular cross-sections. The values given in column 2 as diameters are the "effective diameters," or four times the hydraulic depth. In these two series the outer flue was the same as used in series D, the diameter of the core being 1.59 in. for Series B and 1.36 in. for Series C.

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and are plotted in Fig. 13. The straight line drawn through these to give the smoothed values is represented by

$$B = \bar{1}.56 - 0.30\,d$$

which is Equation [2][1].

28 This completes the account of the development of the formulæ proposed. It now remains to consider their application to other independent experiments and to consider critically some portion of the work described above.

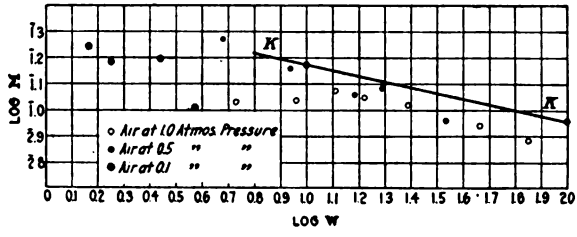

FIG. 14 RELATION BETWEEN COEFFICIENT M AND RATE OF GAS FLOW (W) FROM JOSSE'S EXPERIMENTS
(Line K–K derived from the general formula

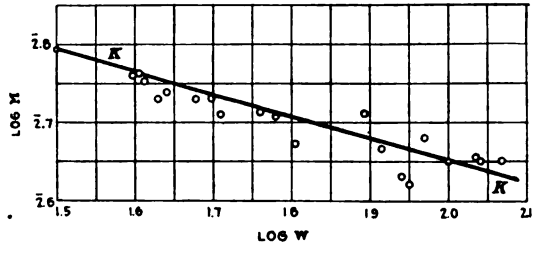

FIG. 15 RELATION BETWEEN COEFFICIENT M AND RATE OF GAS FLOW (W) FROM FESSENDEN'S EXPERIMENTS, SERIES I
(Line K–K derived from the general formula)

APPLICATION OF THE FORMULÆ TO OTHER EXPERIMENTS

29 In addition to those from the seven series of experiments considered above, experimental data from five other series are available for comparison. These are the two series by Fessenden, one by Josse, and two series of the Pennsylvania Railroad locomotive tests.

[1] It must be noted that Equations [2] and [2a] do not represent two phases of the same law but are alternative methods of approximating to the experimental data, of which [2] can be applied to circular and annular flues, and [2a] to circular flues only.

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For these experiments values of M were calculated as before and the values of log M plotted against log W in Figs. 14 to 17. In these figures the points are rather more scattered than in those previously considered, and the straight-line relation between log M and log W is not so clearly marked. This is probably due to a somewhat lower

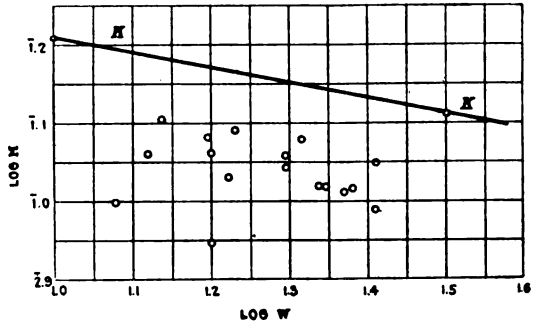

FIG. 16 RELATION BETWEEN COEFFICIENT M AND RATE OF GAS FLOW (W) FROM FESSENDEN'S EXPERIMENTS, SERIES II

(Line K–K derived from the general formula)

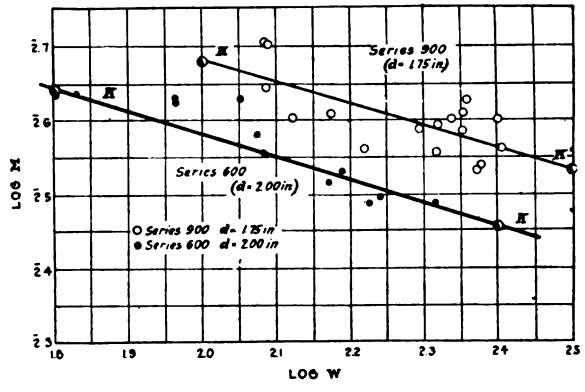

FIG. 17 RELATION BETWEEN COEFFICIENT M AND RATE OF GAS FLOW FROM PENNSYLVANIA RAILROAD LOCOMOTIVE TESTS

(Line K–K derived from the general formula)

degree of accuracy in the experiments, and it was for this reason that these series were used for checking rather than for establishing the formulæ. The values of the coefficients A and m as determined by Equations [3] and [4] for the respective flue diameters are given for all twelve series of experiments in columns 7 and 8 of Table 2. The

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lines corresponding to these coefficients are drawn in in the various figures and marked K–K.

30 In the Josse experiments, Fig. 14, the values of M given by the line K–K derived from Equations [2], [3] and [4] are slightly higher than those calculated from the experiments. The deviation of the line from the points is hardly greater than the discrepancies between the individual points. In view of the fact that no very elaborate precautions were taken to prevent errors in these experiments, it is quite probable that the formula represents the actual conditions at least as closely as do the figures derived from the experimental data. This series is also interesting, as it confirms the indication given by the Nusselt experiments of a critical gas speed at about 5 lb. per hr., $\log W = 0.699$.

31 In the Fessenden experiments the points in Series I, Fig. 15, are very smoothly grouped and could hardly be better represented than they are by the line K–K given by the formulæ. In Series II, Fig. 16, the agreement between the calculated line K–K and the experimentally derived points is apparently not so close, but in this case the experimental conditions were such as to give a comparatively large variation in the coefficient M for a small variation in the heat absorption. In Fig. 16, for a rate of gas flow of 19.7 lb. of gas per hr., that is, $\log W = 1.295$, the value of $\log M$ from the formulæ as shown by the line K–K is $\bar{1}.15$, while the experimental points show $\log M = \bar{1}.05$. The experimental conditions corresponding to this rate of flow of gas show a temperature drop from 2003 deg. fahr. to 281 deg. fahr. in a flue 10.44 ft. long. The use of the calculated value of the coefficient M would change the outlet temperature from 281 to 238 deg. fahr., making the temperature drop 1765 instead of 1722 deg. This only means a difference of 2.5 per cent in the amount of heat absorbed from the gas, which is within the range of errors of observation in these experiments. There is therefore no real conflict between the experimental data and the formulæ proposed.

32 The Pennsylvania Railroad locomotive tests, Fig. 17, show remarkably close agreement between the points derived from the experiments and the lines K–K given by the formulæ. A noticeable feature in this figure is the difference shown by the experiments in the values of the coefficient M in the two series of tests. The boiler-flue diameter was 1¾ in. in Series 900 and 2 in. in Series 600, and the difference between the values found by experiment for M in the two series corresponds exactly to the difference as calculated from the formulæ for the two different flue diameters.

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CONCLUSIONS

33 The formulæ derived from the seven series of Jordan, Nusselt, and Babcock and Wilcox experiments are closely confirmed as to accuracy of results by the five series of Fessenden, Josse, and Pennsylvania Railroad experiments.

A DIAGRAMMATIC METHOD OF CONSIDERING THE PROCESS OF HEAT TRANSFER

34 *Mechanism of Heat Transfer.* The following discussion is offered as a means of obtaining a general mental picture of the complicated processes involved in the transfer of heat between gas and wall. The discussion concerns itself throughout with the action of a hot gas in a cooler flue, but with the necessary reversal of terms it could be applied to a cool gas and a warmer flue.

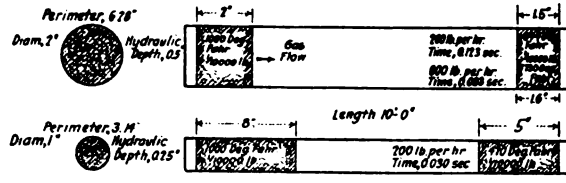

FIG. 18 EFFECT ON TEMPERATURE DROP OF CHANGING VELOCITY OF GAS (*a*) BY CHANGING WEIGHT OF GAS, AND (*b*) BY CHANGING DIAMETER OF FLUE

35 First consider the effect shown by the formulæ to follow from an increase in the rate of flow of gas, as in Fig. 18. Two flues are shown, one 2 in. and the other 1 in. in diameter. They are assumed to be 10 ft. long, with a wall temperature of 380 deg. fahr., and to both air is supplied at an inlet temperature of 1000 deg. fahr. If the rate of flow in the 2-in. flue be 200 lb. per hour the outlet temperature will be 644 deg. fahr., 58 per cent of the absorbable heat being taken up. An increase in the rate of flow to 800 lb. per hour, quadrupling the linear speed of the gas, increases the outlet temperature to 730 deg. fahr., reducing the efficiency of absorption to 45 per cent. Owing, however, to the larger amount of air passing in the same time, the effectiveness of the flue, that is, the heat absorbed per square foot per hour, is increased about 3.3 times. In the 1-in. flue carrying 200 lb. of air per hour the linear speed of the gas is four times that first considered, but the outlet temperature is 470 deg. fahr., the efficiency of

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absorption being 87 per cent. Although the absorbing surface is only half that of the 2-in. flue, the heat absorbed is nearly 60 per cent more for the same weight of gas. It is found that the heat absorbed per hour per square foot of surface in the three cases is, for the 2-in. flue 3700 B.t.u. for 200 lb. per hr. and 11,000 B.t.u. for 800 lb. per hr., and for the 1-in. flue 10,800 B.t.u. for 200 lb. per hr. Thus the effectiveness of the surface is increased by an increase in the linear gas speed in approximately the same proportion whether the increase in speed is due to an increase in gas flow or to a decrease in flue diameter. The increase in gas flow, however, reduces the efficiency, while the reduction in diameter, because of the resulting reduction in hydraulic depth, increases the efficiency.

36 The underlying principles are more clearly brought out by considering a short element of gas in each flue. For convenience 1/10,000

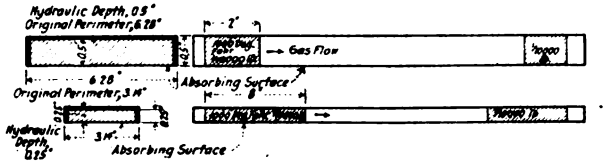

FIG. 19 FLUES OF FIG. 18 DEVELOPED INTO RECTANGULAR SECTIONS HAVING A WIDTH EQUAL TO ORIGINAL PERIMETER AND DEPTH EQUAL TO HYDRAULIC DEPTH

(Heat transfer is supposed to take place only across the lower side of the section, the surface of this side being equal to the original surface of the flue)

lb. is taken. At the inlet temperature of 1000 deg. fahr. the length of this element will be 2 in. in the 2-in. flue and 8 in. in the 1-in. flue. The length of the element will contract as the temperature falls along the flue, and on the basis of the mean temperature in each case the surface of the 1/10,000-lb. element in contact with the flue will be 11 in. and 11.3 in. in the 2-in. flue and 20.4 in. in the 1-in. flue. The time taken by the element to pass through the flue will be respectively 0.123 sec., 0.030 sec. and 0.033 sec. It seems obvious that the decrease of efficiency in the second case is due to the decreased time of contact between gas and flue, while in the third case the greater surface and lesser hydraulic depth more than offset the shorter time.

37 For further examination it is convenient to consider the two flues developed as in Fig. 19 so as to be of rectangular section, with the original perimeter as width and the mean hydraulic depth as height. As represented thus, three walls of the rectangular section must be

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considered as perfectly non-conducting, all of the heat transmission taking place through one wall whose width is equal to the length of the former perimeter.

38 The element of gas passing along the flue consists of a large number of particles in rapid motion in all directions, and the transfer of heat must take place by the impact of the particles on the absorbing surface, each particle at each impact giving up a certain proportion of the heat it carries. Then the amount of heat given up by the gas will depend on the number of impacts made on the absorbing surface and on the temperature at which these impacts are made. At the instant the gas element enters the flue, the number of particles in the act of impinging on the surface is proportional to the area of the surface of the element. The velocity normal to the surface, that is, the velocity producing impact, is proportional to the gas temperature. Each particle gives up an amount of heat proportional to its temperature, and rebounds with a lower temperature and consequently with a lower normal velocity. This impact and the rebound are repeated constantly so long as the gas element is in the flue, the mean distance traveled between successive impacts being proportional to the mean hydraulic depth. The effect of this is that the interval between successive impacts increases and the amount of heat given up at each impact decreases, so that the rate at which the element of gas loses heat decreases progressively with the time, that is, with the passage of the element along the flue.

39 From this statement of principles it appears that the amount of heat given up by the element of gas depends on four factors: (1) Initial temperature of gas; (2) Area of contact between gas element and flue; (3) Hydraulic depth; (4) Length of time gas element remains in flue. A decrease in the hydraulic depth or an increase in any of the other three factors will increase the amount of heat transferred.

40 The connection between these factors and the dimensions of the flue and the rate of flow of gas can be seen from Fig. 20. It is evident from a comparison of flues A, B and C that when the hydraulic depth is the same, as is the case in A and B, the area of the surface of the element is independent of the perimeter, and consideration of C shows that the area of the surface varies inversely with the hydraulic depth. A reduction in depth thus has a double effect in accelerating the transmission of heat, since it not only decreases the travel of the particles but also increases the area of the contact surface of the element.

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41 When two flues have the same depth, as A and B, the gas element has the same area of surface in both, and the temperature drop will be the same when the linear gas speed is the same, so that the time for the element to pass through the flue will be the same in both cases. The same linear speed will be secured when the flue A having twice the perimeter carries twice as much gas, or generally when the rate of gas flow per inch of perimeter is the same for both flues. It would be equally true to say that the temperature drop is the same when the rate of gas flow per square inch of sectional area is the same, but this complicates matters by reintroducing the hydraulic depth since the area is the product of perimeter and hydraulic depth.

42 The general relation between conditions and results can now be seen. The initial temperature determines the rate at which the

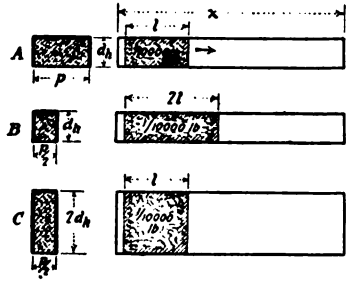

FIG. 20 EFFECT OF PERIMETER (p) AND HYDRAULIC DEPTH (d_h) ON AREA OF SURFACE CONTACT PER WEIGHT ELEMENT OF GAS

heat transfer begins. The hydraulic depth determines the area of contact surface and the length of travel between impacts of the particles. For a given hydraulic depth the rate of gas flow per inch of perimeter determines the linear speed, which in conjunction with the length of flue fixes the time that each unit of gas is in contact.

43 This method of analysis leads to the belief that the linear speed of the gas is only of importance as it affects the length of time that the gas remains in the flue. This conclusion though supported by the experimental evidence cannot be definitely established without more experiments with flues of an annular or rectangular section. With circular flues a change in perimeter involves also a change in hydraulic depth, and to make a direct comparison of the effect of perimeter as in flues A and B of Fig. 20 the depth must remain constant while the perimeter is changed. Previous investigators have

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assumed that linear speed was of direct importance, and to explain its effect have conceived a dead film of gas on the flue surface which was scrubbed away by high speeds. In the author's opinion this is unnecessary, and the result of high linear speed is more easily explained by noting that in relation to the unit weight of gas the effect of high speed is to reduce the time of contact and thus to reduce the loss of heat in passing over a given surface; while in relation to the unit of surface high speed brings a greater weight of gas over the surface and thus increases the amount of heat absorbed in a given time. For the gas, high speed decreases the efficiency of absorption; but for the heating surface the effectiveness is increased. If the older view of the scrubbing action of speed is accepted, both efficiency and effectiveness should be increased.

44 *Gas Temperature.* In setting out the various formulæ for change of temperature along the length of the flue, the temperature of the gas at various points along the flue has been spoken of. This was done with the understanding that the "temperature of the gas" in this sense is a term needing careful definition. In any section of the flue perpendicular to the longitudinal axis the temperature will vary from center to wall. The gas therefore has no definite temperature at that section, but the term "gas temperature" as used in the paper is to be understood as meaning the mean temperature of the gas crossing the section under consideration, that is, the temperature at which the gas if uniformly heated would carry past the section the same amount of heat as is actually carried. This temperature cannot be measured directly by a mercury thermometer or by a thermocouple. Nusselt measured the mean temperature, apparently with a fair degree of success, by means of a resistance thermometer formed of a spiral of wire wound on a mica cross in such a way as to traverse practically the whole sectional area of the flue. In this connection he points out that with pyrometers or bulb thermometers the radiation effect between instrument and flue wall will prevent accuracy of measurement.

45 *Heat Transfer and Loss of Head.* On considering the action of heat transfer as outlined above it will be apparent that there must be an intimate relation between the rate of heat transfer and the loss of head by the gas. As each particle impinges on the flue wall it loses (or gains) a certain proportion of its heat, and at the same time must, unless the flue wall be perfectly smooth — which is of course physically impossible — lose some of its velocity in the direction of the longitudinal axis of the flue.

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46 Nusselt pointed out that Osborne and Stanton have dealt with this phase of the question mathematically, and Stuart[1] in discussing the performance of coolers for lubricating oil says that in the case of the oil and of the water flowing through the coolers the relative friction drops are of the same order as the relative heat-transfer factors.

47 The laws governing the loss of head by a fluid passing through a flue are still but imperfectly established, and it is suggested that a formula of the type given in the paper for heat transfer might be worked out to serve as a general formula for loss of head.

48 Such a general formula would be valuable, as loss of head represents the price that must be paid for heat transfer. In any attempt to increase the rate of heat transfer by increasing the rate of flow of the gas, the limit is set by the loss of head. Beyond a certain point the loss of head, or in other words the amount of energy required to drive the gas through the flue, makes the gain in heat transfer unremunerative.

[1] Journal Am. Soc. Naval Engineers, May 1917.

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APPENDIX NO. 1

DISCUSSION OF THE EXPERIMENTAL DATA AND HEAT-TRANSFER FORMULÆ OF OTHER AUTHORS

49 The first part of the paper presents the formula proposed by the writer for practical use and describes briefly the experiments on which it is based. It is now proposed to describe in greater detail and to examine more critically the experiments which have been used and the various formulæ which have been offered in connection with them.

50 The bibliography of Appendix No. 3 serves to show the sources of the experimental data and to put on record the information the author had before him in writing the present paper. While not pretending to completeness, it is believed to cover most of the important work on the subject published since 1909. The whole field prior to that date is covered by the exhaustive bibliography prepared by Prof. W. E. Dalby in 1909 for the Institution of Mechanical Engineers.

HEAT-TRANSFER FORMULÆ

51 Before considering in detail the experimental data, a brief review will be made of the methods and formulæ used by the various writers in interpreting their experiments.

52 The classic paper to which all refer is that published by Osborne Reynolds in 1874, in which he gave as the law of heat transfer between gas and flue wall

$$h = A + B\frac{W}{a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [7]$$

where

h = number of heat units transferred between gas and flue per unit of time, per unit of surface, per degree of temperature difference
W = weight of gas flowing per unit of time
a = sectional area of the flue
A and B = constants.

53 This type of expression was used by Jordan. The fundamental assumption is that in a short length of a given flue with a given rate of gas flow the amount of heat transferred per square foot of heating surface per hour is proportional to the temperature difference between gas and flue. From this assumption the relation between the gas temperatures T_1 and T_2 measured at any two sections x feet apart along the flue and h the coefficient of heat transfer is developed as follows:

54 In the flue element of length dx and diameter D, the heating surface is $\pi D\,dx$, and if the gas temperature be T and the flue temperature t, the element of heat dq transmitted per hour will by assumption be

$$dq = h\,(T - t)\,\pi D\,dx.$$

At the same time, if dT be the element of temperature lost by the W lb. of gas

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flowing through this flue element in one hour and C_p the specific heat of the gas at constant pressure, it follows that

$$dq = -C_p W\, dT$$

and by combining these equations,

$$h\pi D \int_0^x dx = -C_p W \int_{T_1}^{T_2} \frac{dT}{T - t} \quad \ldots\ldots\ldots\ldots\ldots\ldots [8]$$

from which it follows that

$$h\pi D x = C_p W \log_e \frac{T_1 - t}{T_2 - t} \quad \ldots\ldots\ldots\ldots\ldots\ldots [9]$$

55 After computing values of the heat-transfer coefficient h by this equation from his experiments, Jordan concluded that Osborne Reynolds's expression, Equation [7], was valid and that the coefficient A was a constant having the value 5.4, while the coefficient B depended on the flue diameter and on the gas temperature. The Babcock and Wilcox Company also used the Osborne Reynolds expression, but in connection with higher temperatures and other flue lengths they found B to be a constant equal to 2.0 and A to vary with the gas temperature, but not in accordance with the expression given by Jordan.

56 At about the time of Jordan's experiments Nusselt was working on the same problem, endeavoring to start from first principles by developing a general equation from the laws of motion in which the constants could be determined by experiment. In practice there was a considerable break between the equation developed from theory and that devised to express the experimental results. Nusselt's equation, which is therefore mainly empiric, is as follows:

$$h = B \frac{L_w}{D^{1.786}} \cdot \left(\frac{LW}{C_p}\right)^{0.786} \quad \ldots\ldots\ldots\ldots\ldots\ldots [10]$$

where B is supposed to be a constant having the value 12.93 in metric units. L is the heat conductivity of the gas at the mean gas temperature, L_w the conductivity of the gas at the flue temperature, D the flue diameter, W the weight of gas per unit of time, and C_p the specific heat at constant pressure.

57 This expression with a constant value of B fitted Nusselt's experiments fairly well, but is not applicable to other flue lengths and to other temperature conditions. The author has applied the expression to the majority of the experiments covered by the present paper, and has found that the coefficient B is not a constant, but is approximately of the form

$$B = B_1 + B_2 \frac{T_1 - T_2}{l}$$

in which B_1 is probably a constant and B_2 dependent on the section of the flue. Nusselt in a second paper recognized that the coefficient of heat transfer was dependent on the flue length, but did not establish any law.

58 The various expressions for the heat-transfer coefficient h defined as above have failed to achieve universality because of a fundamental defect. The heat transferred per square foot of surface per hour is assumed to depend only on the difference in temperature between gas and flue; but the experiments show that this assumption is not justified, as the rate of transfer is also dependent in some way on the actual gas temperature. That is to say, in Equation [9] h is not constant as regards x and T and therefore cannot properly be left outside of the integration. Consequently, the results of this integration are meaningless. It

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is a curious fact that none of the experimenters referred to above has noticed that by showing that the coefficient h varied with the temperature, they vitiated Equation [9] which had been used to compute this coefficient.

59 Leprince-Ringuet, after a study of Nusselt's and Jordan's work, as well as experiments by Carcanagues, Ser, Stanton, and the Pennsylvania Railroad, proposed a modification of the Nusselt formula, introducing an exponential function of the flue length and making Nusselt's exponent n vary with the flue section. This was a step in advance, but the most hopeful suggestion seems to be that made by Hedrick to the effect that the rate of heat transfer in the flue element is dependent on the amount of heat in the gas. Hedrick and Fessenden from this assumption developed the following expression for the gas temperatures T_1 and T_2 at a distance of x ft. from each other along a flue having a temperature t:

$$\text{lolog } T_1/t - \text{lolog } T_2/t = Mx \quad \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

where lolog means "the logarithm of the logarithm," M is a constant for a given flue and a given rate of flow of gas, and all temperatures are measured from absolute zero. Fessenden and Haney from the same basic assumptions developed the expression in the form

$$\text{lolog } H_1/H_w - \text{lolog } H_2/H_w = Mx \quad \ldots\ldots\ldots\ldots\ldots\ldots [11]$$

where H_1 is the heat above absolute zero carried by the gas at the temperature T_1 and H_2 and H_w have similar meanings for the temperatures T_2 and t. They also attempted to establish the relation between the coefficient M and the flue section and the rate of flow of gas. The experimental data available were not varied enough to make the attempt successful.

60 It seems that in developing Equations [1] and [11] the one from the other, there is a momentary confusion as to the constancy of the specific heat of the gas. The point is not important unless the fundamental law of heat transfer can be established on an exact basis. The author prefers not to attempt this, but to consider Equation [1] as an empiric formula to be judged pragmatically by the practical value of the results given. Taking this equation as a basis the present paper shows the results of applying it to some two hundred diverse tests, and the relation thus found to exist between the coefficient M and the flue section and the rate of gas flow.

61 In this work the choice between Equations [11] and [1], based respectively on heat content and temperature of gas, was made on the grounds of practical convenience only. The equation relating the temperatures was chosen because in practical work it is more convenient to deal with the absolute temperature of a gas than with the heat content above the absolute zero.

EXPERIMENTS

62 The characteristic features of the various series of experiments are given in Table 1, and are briefly referred to in the paper. They will now be dealt with in greater detail.

63 *Jordan's Experiments.* In these experiments air preheated to the desired degree was passed downward through a copper pipe surrounded by a cast-iron casing. Cooling water flowed upward in the space between pipe and casing. The temperature of the air and of the water at inlet and outlet was measured by thermometers, while four thermocouples, one near the inlet, one near the outlet and the others at two intermediate points, were arranged to measure the temperature of

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the flue half way of its thickness between the inner and outer surfaces. The individual readings of these thermocouples are not given, but Jordan computed from them the temperature of the flue midway of its length and midway between its inner and outer surfaces and gives this as the mean flue temperature. The weight of air passing was determined from the amount of heat given up to the water and from the drop in temperature of the air, assuming a specific heat of 0.238 for the air. The only two weak points in an otherwise highly reliable series of experiments are the method of measuring the outlet temperature of the air and the assumption of a constant specific heat for the air in order to determine the rate of flow. If the values given by the Babcock and Wilcox Company for the instantaneous specific heat of oxygen and nitrogen be taken, the instantaneous specific heat of dry air at constant pressure is found to be

$$C_p = 0.230 + 0.0000240\,t \quad \ldots\ldots\ldots\ldots\ldots\ldots [7]$$

where t is the temperature in degrees fahrenheit. Jordan's air temperatures range from 250 to 750 deg. fahr., so that by this formula the specific heat should range from 0.236 to 0.248 instead of having a constant value of 0.238. In the extreme case there may be a difference of about five per cent between the amount of air determined by the formula for variable specific heat and that found by Jordan using the constant specific heat. The possible gain in accuracy did not seem to be commensurate with the labor of recalculating all of the experiments, and Jordan's figures for rate of air flow have been used.

64 In computing the values of the coefficient M for the present paper the flue temperature is taken at the figure given by Jordan for the mean flue temperature, that is, the temperature of the flue as measured midway between its inner and outer surfaces and halfway between its ends. In a rigidly accurate mathematical expression of the law governing the drop of temperature it is probable that in Equation [1], or $\log T_1/t - \log T_2/t = Mx$, the temperature ratios T_1/t and T_2/t should be based on a value for t corresponding to the mean temperature of the inner flue wall. In practical work, however, the inner-flue-wall temperature is seldom known, and it is desirable to have a formula which uses the ratio of gas temperature to temperature of fluid surrounding the flue. In most of the other experiments this surrounding temperature has been taken as flue temperature. In the Jordan experiments, however, the temperature of the surrounding fluid varied from end to end of the flue and there is some uncertainty as to how the mean temperature of the flue surface either inner or outer should be measured. In view of this and having in mind the fact that the variations in flue temperature are small compared with the other temperatures, it appeared to be unimportant to attempt any great refinement in this direction and Jordan's figure for mean flue temperature was used. Figs. 4 to 9 show the individual points plotted in determining values for the coefficient M in the five series of Jordan experiments. The lines B–B are all drawn as explained earlier in the paper by selecting a center point Z in each plot and drawing straight lines through these center points and through the point ($\log M = \bar{1}.87$, $\log W = \bar{3}.77$) which is common to all of the plots.

65 These B–B lines then are all represented by the equation

$$\log M = \bar{1}.87 - (2.23 + \log W)\,m \quad \ldots\ldots\ldots\ldots\ldots\ldots [5a]$$

where m varies with the effective diameter of the flue. The values of m found for each of the lines is plotted as a point in Fig. 13, and a straight line drawn to represent these points. The values of m given by this straight line for the various flue

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diameters are then used to draw the K–K lines in the individual plots Figs. 4 to 9. The difference between the B–B and the K–K lines in each case is due to the deviation of the corresponding point from the line in Fig. 13. The discrepancy is not large except in Series D, Fig. 6. By referring to Fig. 13 it will be seen that Series D and the Babcock and Wilcox series, though made with flues of practically the same diameter, give different values for the coefficient m. In placing the line in Fig. 13 it was thought better to give the Babcock and Wilcox point more weight than that for Series D. This gives a closer agreement between the line and the other points, and the Fessenden and Pennsylvania Railroad tests appear to justify this course. It may be noted that if the weight of air in Series D were redetermined on the basis of variable specific heat, the distance between the lines B–B and K–K in Fig. 6 would be reduced about one-half.

66 *Babcock and Wilcox Experiments.* The apparatus consisted of a 20-ft. copper flue 2 in. in inside diameter surrounded by twenty individual water jackets, to each of which cooling water could be supplied and weighed. Through the flue the products of combustion from an illuminating-gas furnace were drawn by suction and passed through a cooler and through a dewpoint box to the discharge. The following brief statement given as to the methods used in making calculations illustrates the functions of the various parts of the apparatus:

67 "The determination of the dewpoint of the gases after leaving the cooler determines the density of the water vapor in the gases. With the dewpoint known and an analysis of the gases passing through the dewpoint box, the proportionate parts by weight of the various constituents of the gas may be determined. This in turn, together with the gas temperature entering and leaving the cooler, enables the mean specific heat of the gases through the cooler to be calculated. With the specific heat, the temperature of the gases entering and leaving the cooler, the temperature of water entering and leaving the cooler, and the weight of water passing through the cooler known, the weight of the gases may be calculated. The external flue temperature was measured by means of thermocouples in a number of the jackets and an expression developed from which the flue temperature in any jacket could be found from the cooling-water temperature and the amount of heat being given up by the flue in that jacket."

68 In the published account of the experiments detail figures are given for only one representative experiment, but through the courtesy of Mr. Arthur D. Pratt, the Babcock and Wilcox Company have placed at the author's disposal the figures for six other tests.

69 In studying these figures for the present paper it was found that if the logs of the temperature ratios were plotted to the scale indicated in Fig. 3 the points fell very close to a straight line, but that when the values of M were calculated from one point to another along the flue considerable variations were found. Eventually the values of M used in Fig. 9 were based on the fall of temperature in the gas between its exit from the first jacket and its exit from the eighteenth jacket, that is, over a flue length of 17 ft. In the computations the flue temperature used was the mean of the temperatures as given in the experiments for the 17 jackets concerned.

70 *Nusselt's Experiments.* The heat-transfer flue employed by Nusselt was of brass, 22.01 mm. (= 0.868 in.) in inside diameter and about 5.9 ft. long. It was surrounded with a casing, and through the intermediate space steam could be passed. The flue temperature was measured by a thermocouple. The gas at

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room temperature entered the flue at one end and escaped at the other, the volume admitted being measured by an accurately calibrated gas meter. When a steady flow had been established the temperature was measured at two points successively by a resistance thermometer. This consisted of chemically pure platinum wire 0.1 mm. in diameter wound in four turns spirally on a mica cross which was carried in turn on a fiber cross fitting the flue. The fiber cross was carried on the end of a small brass tube extending through the stuffing box at one end of the flue, and could thus be moved along the flue. Nusselt gives detail results of 100 experiments, of which the following are used in the present investigation:

Nos. 1 to 13: 13 experiments with air at a pressure of about 14 lb. per sq. in. abs.

Nos. 91 to 100: 10 experiments with air at a pressure of about 14 lb. per sq. in. abs.

Nos. 46 to 57: 12 experiments with air at a pressure of about 140 lb. per sq. in. abs.

Nos. 70 to 81: 12 experiments with lighting gas at atmospheric pressure.

Nos. 82 to 90: 10 experiments with CO_2 at atmospheric pressure.

The series of experiments 91 to 100 was run with an entrance flue 6.55 ft. long set ahead of the flue to eliminate any eddy currents which might be set up by the gas entering the flue at right angles to its length. The differences in results as shown in Fig. 11 are not great. Contrary to expectation, the heat transfer with the entrance piece was slightly more rapid than without it.

71 *Josse's Experiments.* These were made with an apparatus very similar to Nusselt's, but much less elaborate as to details. The flue consisted of a steam-jacketed tube of 23 mm. (= 0.905 in.) inside diameter and 1.320 m. (= 4.34 ft.) long. Air was drawn through the flue by an air pump, its volume being measured by a gas meter before entering. Temperatures of the air at inlet and outlet and of the steam in the jacket were measured by mercury thermometers. This means that the temperatures given have not the authority of those determined by Nusselt's more exact methods. Of the 17 experiments reported by Josse and used in the present paper seven were made with an air pressure in the flue of 1.03 atmos. (= 14.7 lb. per sq. in.), five with a pressure of 0.51 atmos. (= 7.2 lb. per sq. in), and five with a pressure 0.104 atmos. (= 1.5 lb. per sq. in.), all pressures being absolute. These experiments confirm the indication given by Nusselt's regarding a critical speed of the gas. The line K–K, which agrees reasonably well with the points, is determined by the general formula for a flue of the diameter used by Josse.

72 *Fessenden's Experiments.* The general arrangement of the apparatus was very similar to that used by the Babcock and Wilcox Company. In Series I the flue was 10.95 ft. long by 1.816 in. in inside diameter, while in Series II there were two parallel flues each 10.44 ft. long and 0.816 in. in inside diameter. In each case the flue (or flues in Series II) was enclosed in ten jackets, into which water was fed with the intention that it should boil at atmospheric temperature. In a number of the experiments in Series II, however, the loss of heat was so rapid that the water in the jackets near the end of the flue did not boil. This may account for the lower degree of consistency shown by the figures in Series II. The products of combustion from a gas furnace were forced through the flue and temperatures measured on entering and on leaving the flue. The rate of gas flow was determined by pitot-tube measurements at the discharge end in connection

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with temperature and pressure measurements, and checked by computing the weight of gas from the specific heat, temperature drop and total heat given up. Fessenden, by measuring the heat absorbed in each of the ten jackets, was able to determine the loss of heat and the fall in temperature along the flue in each experiment. The values used for the coefficient M in plotting the points in Figs. 16 and 17 are those given by Fessenden as representing the mean slope of the line for the lolog H/H_w along the flue. The lines K–K are drawn from the general formula giving the slope of the line for lolog T/t, and strictly speaking the points should have been recalculated on the basis of the temperature ratio T/t instead of the heat-content ratio H/H_w. This was done in a few cases and the difference was found to be so slight that Fessenden's figures were used as they stood. The point is not of the first importance since the plots are used for checking the general accuracy of the formula and not for establishing exact figures.

73 *The Pennsylvania Railroad Experiments.* The Pennsylvania Railroad experiments are representative tests of locomotive boilers made on the company's locomotive testing plant. Series 600 was made with the plant at St. Louis and Series 900 after its removal to Altoona. The boiler in Series 600 had 273 flues 18.75 ft. long and 2 in. in inside diameter, while that in Series 900 had 315 flues 15 ft. long and 1.75 in. in inside diameter. In each series the boilers were run under normal conditions at various rates of combustion. The firebox and smokebox temperatures were measured, and these are the inlet and outlet temperatures used in finding the coefficient M. The flue temperature was assumed to be the same as the temperature of the steam and water surrounding the flues in the water. To determine the weight of gas passing through the flues a special calculation is necessary. In a locomotive a very considerable percentage of the coal fired escapes through the stack unburned and consequently the weight of gas per pound of coal burned, as found from the flue-gas analysis, and the weight of coal fired are not sufficient to determine the actual weight of the products of combustion. The author[1] has shown that if the heat absorbed by the boiler per pound of coal fired has been measured and if the heat lost in the smokebox gases per pound of coal burned is known from the flue-gas analysis and the smokebox temperature, then an equation can be established and solved for that unknown percentage of coal fired which is actually burned. The method has been used by Prof. W. E. Dalby and also, but without acknowledgment, by Royds.[2] Taking into account the indirect methods of determining the weight of gas in these locomotive experiments and the comparatively rough methods of measuring the gas temperatures, the agreement between the plotted points and the lines K–K drawn from the general formula is extremely satisfactory. The points show clearly the difference in the rate of fall of temperature due to the difference in flue diameter in the two series.

74 Since the paper was written the author has secured a copy of The Transmission of Heat into Steam Boilers, by Henry Kreisinger and Walter T. Ray, Bureau of Mines Bulletin No. 18, 1912. This describes experiments on heat transmission made with miniature boilers, and discusses the general theory. Unfortunately an attempt was made to measure inlet and outlet gas temperatures by means of mercury thermometers, and as a consequence there is very serious

[1] Proc. Inst. M. E., March 1908.

[2] Institute of Engineers and Shipbuilders in Scotland, January 19, 1915.

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reason for doubting the accuracy of the results. The general conditions under which heat is transmitted are discussed at considerable length and the conclusions, so far as a general view of the subject is concerned, are in harmony with the work of other observers. In some cases, however, statements are made with greater definiteness than is warranted by the conditions of the experiments. The relation between loss of pressure and rate of heat transfer is discussed at length.

APPENDIX NO. 2

EXPERIMENTAL DATA

75 The original data on which all the calculations in the paper have been based are given in thirteen tables prepared by the author, which also give some of the derived figures used in building up the general formula. These tables are on file at the Society's headquarters and may be consulted by any one interested in their contents.

76 The original data embodied in the tables comprise inlet and outlet gas temperatures, mean flue temperature, flue length between the two temperatures, and rate of flow of gas. These particulars are given in every case in the units in which they were reported by the original experimenters, the transformation to the units used in the paper having been made in the course of the calculations.

77 The derived figures given in the tables are all in terms of the units used in the paper, and consist of values of Mx (or the difference between the logs of the temperature ratios), M (obtained by dividing values of Mx by flue length x), log M, and log W, W being the rate of gas flow in pounds per hour per flue.

APPENDIX NO. 3

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DISCUSSION

E. A. FESSENDEN (written). Mr. Fry's paper is a distinct contribution to the study of the transmission of heat by convection. While much excellent experimental work has been done, apparently no one has heretofore succeeded in correlating and harmonizing the results of many investigators so satisfactorily as is done in this paper. Formulæ showing the relations between factors involved in heat transmission by convection have been proposed in so many different forms that it has been difficult to realize that any connection exists between them. Instead of using these formulæ, proposed by various experimenters, Mr. Fry has gone to the original data and demonstrated that all the results may be satisfactorily represented by a single equation. The data are thus no longer more or less chaotic, but consistent, not only for each separate series of experiments, but for all. That this is true for data gathered under a wide variety of conditions encourages the belief that the real solution of the problem is brought nearer.

The general formula, Eq. [1], proposed at the New Orleans meeting in 1916,[1] was based upon two series of experiments and confirmed by several other isolated sets of data. No attempt was made

[1] Trans.Am.Soc.M.E., vol. 38, p. 407.

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at that time to evaluate the constant M. A little later, a full account of these experiments was published,[1] and an empirical equation was given which satisfied these particular tests, namely,

$$M = 0.195U^{-0.413}$$

where U is the weight of gases per hour per tube multiplied by the hydraulic depth in inches. The experiments did not cover a sufficiently wide range of conditions to warrant proposing this as a general formula.

Fig. 21 shows several sets of experimental data plotted upon $\log M$ and $\log U$ as coördinates. Since $U = Wr$ and $\log U = \log W + \log r$, this method of plotting differs from that used by Mr. Fry only in shifting points horizontally by an amount depending upon r. The amount of displacement is constant throughout any single series, so that the slope of the lines connecting the points is unchanged. The data plotted include all those used by Mr. Fry, and in addition the following:

1 A series of tests made upon a consolidation locomotive[2]
2 Some tests made by the United States Bureau of Mines upon a Heine boiler[3]
3 Some tests made upon single- and double-pass Heine boilers by Abbott and Bement[4]
4 Nicolson's tests upon a Cornish boiler, in which a firebrick plug was inserted in the flue, leaving an annular gas passage 1½ in. wide.[5]

In order to reduce confusion, the separate experimental points for the tests used by Mr. Fry and for the additional locomotive series are not shown, but the heavy lines in the figure represent quite accurately the tests indicated. The light lines are plotted from the author's Equation [2*a*] for flues of circular cross-section. The other three groups of tests did not cover a sufficiently wide range of conditions to permit curves to be drawn to represent them, but they do indicate that the author's Equation [2] for M in its present form does not apply universally. It should be emphasized, however, that these latter data are very much beyond the range of those investigated by the author of the paper. In the Heine boiler the gas pass-

[1] University of Missouri Bulletin, vol. 17, no. 26 (Oct. 1916).
[2] University of Illinois Engineering Experiment Station Bulletin, no. 82.
[3] United States Bureau of Mines, Bulletin 23 (Boiler no. 1).
[4] United States Bureau of Mines, Bulletin 18, p. 155.
[5] Power, Feb. 7, 1911, p. 222.

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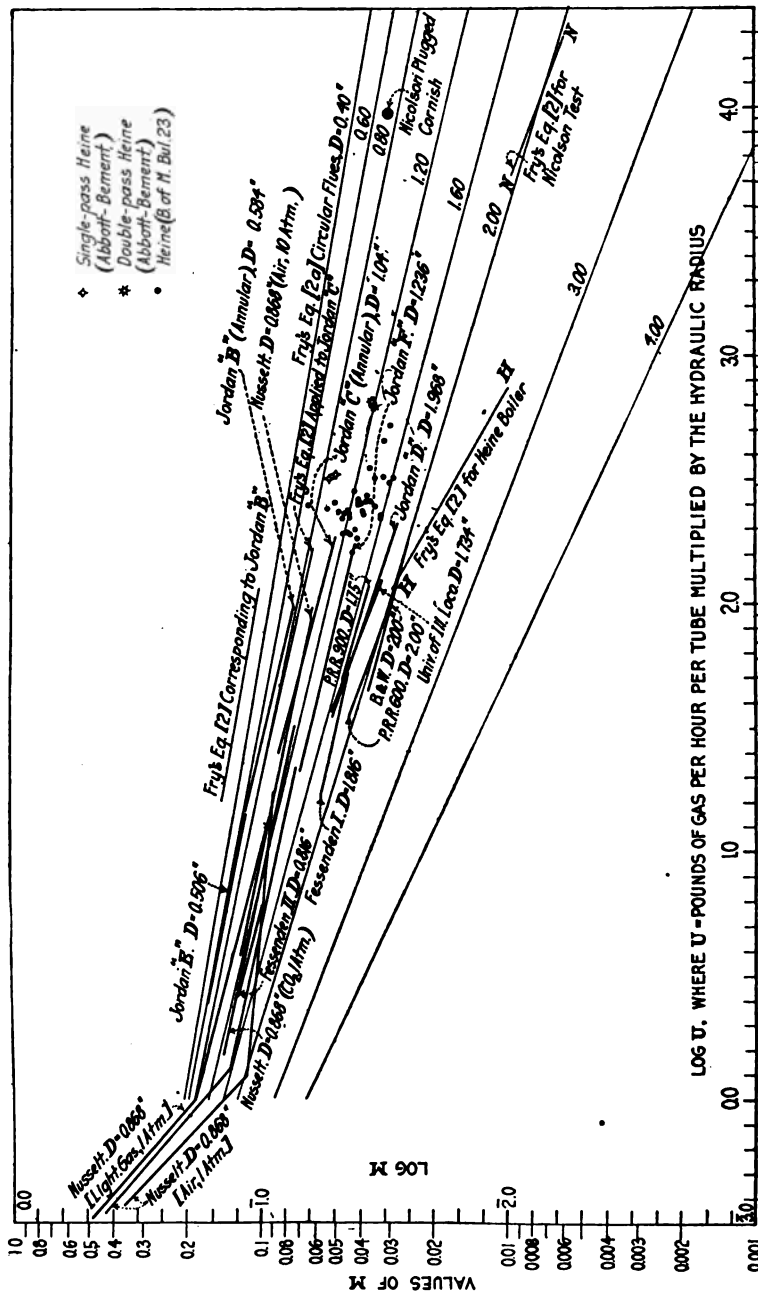

FIG. 21 EXPERIMENTAL DATA ON HEAT TRANSFER PLOTTED UPON LOG M AND LOG U AS COÖRDINATES

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age through the prism occupied by the tubes is not of circular cross-section, but is the space left around 3½-in. tubes on 7-in. centers, staggered. The hydraulic mean depth of the gas passage is about 1.31 in., and for a single tube the perimeter is 10.996 in. In order to conform to the author's Equation [2], the points[1] for tests on the Heine boiler should cluster around the line marked *H-H*. Instead, the actual points indicate values of M about 2¼ times as large as are given by the proposed equation. A similar discrepancy is indicated for the Nicolson experiments.

A somewhat similar discrepancy may be shown for flues of circular cross-section larger than those covered by the experimental data. For example, in an ordinary return tubular boiler with 4-in. tubes, 16 ft. long, operating with 65 per cent overall efficiency and at rated load, with 18 lb. of air per pound of coal, an average of about 135 lb. of gases pass through each tube in an hour. The hydraulic depth is 0.933 in., and by the author's Equation [2] the value of M is 0.00912. If the water temperature is 366 deg. fahr. (corresponding to 150 lb. gage pressure) and the flue-gas temperature 600 deg. fahr., the temperature of the gases entering the tubes by Equation [1] is only 730 deg. fahr. Under the operating conditions assumed above we might reasonably expect a furnace temperature of 2000 deg. fahr. to 2200 deg. fahr. The temperature drop from furnace to tube entrance would then be about 1300 deg. fahr. to 1500 deg. fahr.; i.e., about 91 per cent of the total heat absorbed by the boiler is taken up by the shell by radiation from the firebox and by convection in the combustion chamber, leaving only about 9 per cent for absorption by the tubes. This is decidedly inconsistent with our usual ideas as to the value of the tube surface. If the temperature at entrance to the tubes is assumed to be, say, 1700 deg. fahr., the value of M is 0.0325. Rather curiously, considering its limited basis, the value of M for the same conditions computed from the formula $M = 0.195U^{-0.413}$, mentioned above, is 0.0284. In the footnote given on page 725 it is stated that Eqs. [2] and [2*a*] are both applicable to flues of

[1] The boiler used in the Bureau of Mines tests had tiles completely encircling the lower row of tubes, forming a tile roof to the furnace. In computing M the furnace temperature was taken as the temperature at the entrance to the tube bank, and for the end of the tube bank the temperature was taken as that of the flue gases. Thus the assumed temperature drop through the tube bank is undoubtedly too high, with a corresponding error in M. This does not account for the large departure in the values of M from Mr. Fry's curve, since fair allowances for the errors in the assumed temperature drop would reduce the values of M possibly 20 to 30 per cent.

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circular cross-section. They do not give exactly consistent results, however. For example, for the return tubular boiler just considered, Eq. [2] gives $M = 0.00912$, while Eq. [2a] gives $M = 0.00812$.

Within the limits of the experimental data investigated, the author has apparently succeeded admirably in adapting the basic formula to widely varying conditions. Beyond these limits, i.e., for tubes larger than 2 in. in diameter and for passages of irregular cross-section, more experimental work is necessary before any very definite extension of the author's formula can be obtained. The Heine boiler tests and the Nicolson test, shown in Fig. 21, suggest that Mr. Fry's straight lines may be tangents to rather flat curves. Inspection of the author's Fig. 13 suggests that possibly the values of B and m, instead of being represented by straight lines, may lie on curves of parabolic form. This would increase B and decrease m for passages of larger "effective diameter" and thus increase M.

E. R. HEDRICK[1] (written). I have myself attempted to secure a formula for the relation between M and W which shall represent the facts throughout the entire range of values of W included in the experiments quoted, but I am not convinced that the formula of the paper can be improved upon. There are reasonable grounds for supposing that there is really a break in the behavior when W has what is called by the author the critical value of (about) 5 lb. per hour. Also it is possible that a different relation for the effect of the flue diameter will have to be worked out when experiments are available in which a greater variety of values of d occur. Possibly the relations suggested by Fessenden and Haney (Univ. of Mo. Bulletin, vol. 17, no. 26) may be found at least helpful in settling this question.

The author refers in Par. 6 to the fact that "no attempt is made to measure the rate of heat transfer." However, it should be emphasized that any formula that gives the temperature (or the heat-content) of the gas in terms of the distance along the tube, implies directly a law for the rate of heat transfer. This is the reason that the Osborne Reynolds hypothesis leads to a definite law for the drop in temperature along the tube, which enables us to compare it directly with such experiments as those of this paper. It was shown in the paper by Professor Fessenden and myself (Trans.Am.Soc.M.E., vol. 38, p. 407) that our formula [18], which is identical in meaning with Equation [1] of Mr. Fry's paper, leads directly to the formulæ [24] and [25] of our paper:

$$d\theta/dx = -m\theta \log_e (\theta/\theta_w)$$

[1] University of Missouri, Columbia, Mo.

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or

$$d\theta/dx = -2.3026\, mR_0\theta_e^{-mx}$$

where the notation is that of our paper. From these, it is but a step to show that the rate of heat transfer (per degree difference in temperature per square foot of heating surface per second) is expressible by the formula

$$\frac{C_p w}{\pi d} \frac{1}{\theta - \theta_w} \frac{d\theta}{dx}$$

where w is the weight of gas passing per second, C_p the specific heat of the gas, and d the diameter of the tube. Hence the rate of heat transfer is proportional to

$$\frac{C_p \theta}{\theta - \theta_w} \log\left(\frac{\theta}{\theta_w}\right)$$

In any event, the rate of heat transfer is certainly not proportional (simply) to the difference in temperature, as is abundantly shown by the experiments quoted in this paper.

J. F. BARKLEY[1] (written). After an extended experimental study along the lines of the subject of the paper, I feel that any equation which includes all the physical factors involved in such a heat transfer will unquestionably be too complicated for practical purposes. It seems to me that there will always be necessary a simple equation, such as that of Osborne Reynolds, including, perhaps, a few of the main physical factors. These together with experimental constants will serve to obtain desired quantities within certain ranges.

The temperatures taken by the author from the B. & W. experiments were derived by calculation, using the specific heat of the gases. The specific heats of gases, particularly at temperatures from about 1500 deg. fahr. up, are not well agreed upon by the best authorities. This variation amounts to several hundred degrees at 2500 deg. fahr. What is needed are some experiments where a heat balance can be taken which would show the possible inaccuracy of the data, plus or minus.

As to the accuracy of the formula, I would like to ask what the maximum possible per cent error would be if one were to solve it for some quantity, say, the length x of a tube.

GOTTFRID L. OSTGREN asked whether there were any published data on formulæ to be used for calculation of heat transfer for large

[1] Asst. Efficiency Engineer, Carnegie Steel Co., E. T. Works, Braddock, Pa. Formerly with the United States Bureau of Mines.

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flues, over 2 ft. in diameter, of circular or rectangular cross-section. Frequently an engineer had to design a furnace where he was using waste-heat gases to heat air in a closed space, for instance, in an annealing furnace, and the question of determining the proper radiating surface in order to obtain a certain temperature in the annealing furnace was rather important. He had had occasion to construct an annealing furnace of that type not very long before, and while he had struck the temperature very closely, he had found that when doors were opened on the two sides of the furnace and the temperature dropped, it took a rather long time to get the temperature back again. By putting conical deflectors inside the flue, where the waste gases were passing, it was possible to obtain more contact between the heat units and the steel flue, which improved the transfer considerably.

D. S. JACOBUS said that the heat-transfer rate of conduction from the gases to the cooling surface was only one of the elements to be considered in designing a boiler. For example, the effect of radiant heat on the tubes nearest the furnace was an important element, and unless this was included in an analysis of efficiency the results would be considerably in error. When it came to the final analysis and securing the maximum efficiency from a boiler, the rate of heat transfer must be considered, and it was necessary to balance up a loss in draft against securing a higher boiler efficiency.

There were a number of elements that had to be taken into account in designing a boiler; for instance, the effect of radiant heat. It was necessary to expose enough of the heating surface of the boiler to the radiant heat to keep the temperature of the furnace within the limit that present-day brickwork will stand. Again, the entering velocities of the gases between the tubes should not be made too high. If the area for the flow of the gases was unduly constricted there might be trouble, especially at the higher ratings at which boilers are run today, when the tubes become fouled through the accumulation of soot, which would lead to an excessive draft resistance.

It was also necessary to provide a sufficient furnace volume and a proper length of travel for the burning gases in order to consume the products of combustion, and also to prevent a blowpipe action on the boiler tubes.

An interesting addition to this valuable paper would be an analysis combining the draft losses with the variation of heat transfer to determine the theoretical proportion of the areas between the tubes for the flow of the gases to give a maximum heat absorption

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for a minimum draft resistance. An answer to this problem had been found by experiment and practice for certain classes of boilers, but it would be interesting to have a theoretical analysis of the proper way of proportioning the area for the flow of the gases.

WILLIAM KENT (written). Mr. Fry has done an interesting piece of work in showing, by means of graphical and mathematical analysis, that all the available results of laboratory experiments on the transfer of heat of flowing gas through the wall of the tube in which it flows may be expressed by the formula of Fessenden and Hedrick. It is to be regretted that he has not gone further and tested the formula by comparing results computed by it with the maximum results obtained in tests of boilers of different types, using tubes that are larger than those used in locomotives. The writer has undertaken to make such a comparison, and the figures obtained show such a wide variation of the results obtained in boiler tests from those derived from the formula as to lead to the conclusion that the formula has no validity or usefulness outside of the narrow range of the laboratory experiments on which it is based. He therefore submits the following study to Mr. Fry, asking his criticism of it.

Assume that 1 lb. of coal of a heating value of 14,600 B.t.u. per lb. of combustible is thoroughly burned in a firebrick furnace, with sufficient air to make 19 lb. of flue gases per lb. of combustible, and that these gases are led through firebrick passages to the flue or flues of a steam boiler. Assuming the mean specific heat of the gas between atmospheric temperature and 2700 deg. fahr. to be 0.28, the theoretical temperature of the fire is $14,600/(0.28 \times 19) = 2696$ deg. above the temperature of the atmosphere (taken at 60 deg.) or 3156 deg. absolute, $= T_1$. If the temperature of the water surrounding the flue is 340 deg., its absolute temperature is 800, $= t$. Then $T_1/t = 3.94$. $\log T_1/t = 0.5955$; $\operatorname{log} T_1/t = \bar{1}.775$. Assume that the boiler consists of thirty-two 2-in. tubes, 15 ft. long. Then its heating surface is $(32 \times 2 \times 3.1416 \times 15)/12 = 251.3$ sq. ft. Let enough coal be burned to drive the boiler at rates of 3, 6, 9 and 12 lb. of water evaporated per hour from and at 212 deg. From these data the results in Table 3 have been calculated.

The figures in columns (2) and (3) are those that have been obtained in practice when all conditions were the most favorable, from many different types of high-pressure boilers without economizers. Abundant justification of these figures may be found in Donkin's Heat Efficiency of Steam Boilers, Barrus's Steam Boiler Tests and the

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writer's Steam Boiler Economy. They correspond with the writer's straight-line formula for maximum boiler efficiency, $E = 81 - 1.33\,[(W/S) - 3]$, in which E is per cent efficiency and W/S the rate of evaporation (see Steam Boiler Economy, 2d edition, p. 316, and The Mechanical Engineers' Pocket-Book, 9th edition, p. 893), also with his more complex formula, based on Rankine's assumption that the heat transmitted varies as the square of the temperature difference and is independent of the diameter of the tubes and of the velocity of the gases.

TABLE 3 HEAT-TRANSMISSION CALCULATIONS

Case	Rate of evaporation	Efficiency, max. %	Lb. water evaporated per lb. coal	Coal per sq. ft. H. S. per hr., lb.	Coal burned per hr., lb.	Gas made per hr., lb.	Gas flowing through one tube W	Log W
1	3	81	12.19	0.246	62	1178	36.8	1.5658
2	6	77	11.59	0.518	130	2470	77.2	1.8876
3	9	73	10.99	0.819	206	3914	122.3	2.0874
4	12	69	10.39	1.155	290	5510	172.2	2.2360
Column	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)

Let us now apply the Fessenden and Hedrick formula to the data given above, expanding them so as to include not only the boiler with thirty-two 2-in. tubes, but also five other boilers: viz., one with two 16-in. tubes and one with four 8-in. tubes, each 30 ft. long, one with sixteen 4-in. tubes and one with sixty-four 2-in. tubes, each 15 ft. long, and one with one hundred and twenty-eight 1-in. tubes 7.5 ft. long, all these boilers having the same heating surface and all supplied with the same quantity of gas at the same initial temperature for the same rate of driving. For the four rates of evaporation, 3, 6, 9 and 12 lb. from and at 212 deg. per sq. ft. of heating surface per hour, the data are:

Diameter of tubes, in. $= d =$	16	8	4	2	1	1
No. of tubes	2	4	16	32	64	128
Length of tubes, ft. $= x =$	30	30	15	15	15	75

The formula is

$$\text{lolog } T_2/t - \text{lolog } T_1/t = Mx$$

or

$$\text{lolog } T_2/t = \text{lolog } T_1/t + Mx$$

$$\log M = B - m \log W/p;\ \log (B - 1.3) = \bar{1}.71 - 0.54 \log d$$

$$\text{lolog } T_1/t = 1.775$$

$$\log m = \bar{1}.36 + 0.37 \log d$$

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The principal figures used in the calculation and the resulting efficiencies are shown in Table 4.

TABLE 4 RESULTS OF HEAT-TRANSMISSION CALCULATIONS

Diameter of tubes, in., $=d$	16	8	4	2	1	1
Length of tubes, ft.	30	30	15	15	15	7.5
Perimeter, in. $=\pi d$	50.26	25.13	12.56	6.28	3.14	3.14
Coefficient B	2.81	2.84	2.93	1.05	1.21	1.21
Coefficient M	0.64	0.49	0.38	0.295	0.23	0.23
W/S	Values of W					
3	589	294.5	73.6	36.8	18.4	9.2
6	1235	617.5	154.4	77.2	38.6	19.3
9	1957	978.5	244.6	122.3	61.2	30.6
12	2755	1377.5	344.4	172.2	86.1	43.1
	Final Temperature of Gases (above 0 Deg. Fahr.)					
3	925	651	626	458	366	474
6	1287	869	785	533	389	534
9	1520	1035	899	591	407	612
12	1644	1151	990	640	419	615
	H_2=British Thermal Units in Gas at Final Temperature					
3	235.7	167.0	159.0	115.4	91.9	119.4
6	334.0	224.2	201.7	134.8	97.6	135.1
9	396.5	270.1	231.9	150.1	102.2	155.4
12	442.5	301.5	256.4	163.2	105.2	156.2
	Efficiency (Per Cent) $= (H_1-H_2)/(H_1-14.75)$					
3	70.7	79.8	80.9	86.6	89.7	86.1
6	57.6	72.2	75.2	84.1	89.0	84.0
9	49.4	66.1	71.2	82.0	88.3	81.4
12	43.3	62.0	67.9	80.3	87.9	81.2

The values of H_2 are obtained by multiplying the final temperature by the mean specific heat between zero and the final temperature, this specific heat being calculated from the approximate formula $C_p = 0.245 + 0.000015t$. H_1 is the heat per pound at the initial temperature, 2696 deg. The mean specific heat between zero and this temperature is taken at 0.285. In obtaining the efficiency we subtract 14.75 from H_1 in the denominator for the heat in 1 lb. of air supplied at 60 deg.

The calculated efficiencies are plotted in Fig. 22, and the position of the straight line of the writer's formula is also plotted for comparison.

In the calculations based on Mr. Fry's formula certain assumptions have been made:

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1 That the fuel is thoroughly burned
2 That the air supply is 19 lb. per lb. of fuel
3 That there is no loss by radiation.

These assumptions correspond to ideal conditions, but they are nearly attained in the best practice. If other conditions had been assumed, such as a certain percentage of loss due to imperfect combustion and to radiation, and a somewhat greater air supply, all of the curves shown in Fig. 22 would have been lowered to some extent, but their relative positions would remain the same; that is, the curve of the 4-in. tube would be far below the curves of the 1-in. and 2-in.

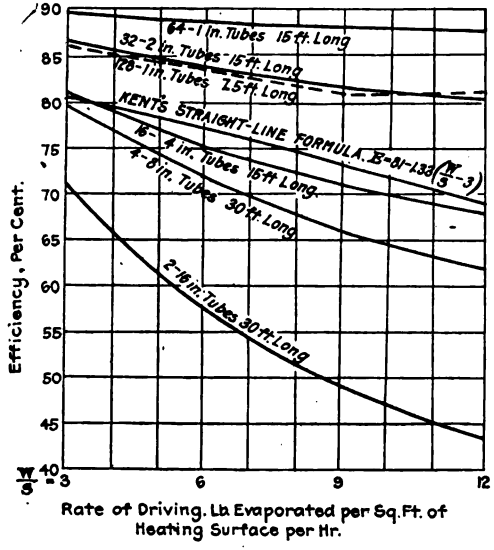

FIG. 22 PLOTTING OF BOILER EFFICIENCIES GIVEN IN TABLE 4

tubes, and the curve of the 16-in. tubes far below the curve of the 8-in. tubes. If calculations for a two-flue Lancashire boiler had been made, the resulting curve would be far below that of the two 16-in. flue boilers.

The straight-line formula involves no assumptions. It is merely the plotting of the best efficiencies obtained in reliable tests of many different types of boiler, including Cornish, Lancashire, Galloway, Scotch marine, fire-tube and water-tube boilers of all sizes and shapes. The results of these tests indicate that the efficiency of a steam boiler is not a function of its type, of the diameter of the gas passages, or

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of the velocity of the gases; but is entirely a function of the conditions under which it is run. These conditions are:

1 Cleanness of heating surface
2 Avoidance of short-circuiting of the gases
3 Quality of the fuel
4 Completeness of the combustion before the combustible gases touch the heating surface
5 Amount of the air supply per pound of combustible
6 Rate of driving, and
7 Avoidance of air leaks in the setting.

Computations from Mr. Fry's formula show results so far from those obtained in actual boiler practice as to lead inevitably to the conclusion as already stated that the formula has no validity or usefulness outside of the range of the laboratory experiments on which it is based.

What is needed to settle this question of the relation of steam-boiler efficiency to the diameter of the gas passages and the velocity of the gases is a series of experiments in which the diameter and the velocity are the only variables, all other conditions, such as extent of heating surface, and rate of burning the fuel, remaining constant. The following method of making the experiment is suggested:

Provide a gas-burning or oil-burning furnace of sufficient size with a sheet-iron casing through which all the air for maintaining combustion is passed, thereby minimizing the loss from radiation. Meter the air as well as the fuel, regulating the supply so as to obtain complete combustion and a very high furnace temperature. Provide a boiler to be connected with the furnace, made of a 12-in. tube 20 ft. long, with one 8-in. tube in it for a gas passage. After running a series of tests with this boiler, with different rates of driving so as to secure an equivalent rate of evaporation ranging, say, from 2 to 15 lb. per sq. ft. of heating surface per hour, substitute for the single 8-in. tube two 4-in. tubes, four 2-in. tubes and eight 1-in. tubes successively, and repeat the tests. In these tests the total heating surface, the perimeter of the gas passages, remains constant, but for a given amount of fuel and air supply the velocity of the gas will vary as the figures 1, 2, 4, 8. The boiler can be run as an air heater, using either steam or waste gases of a temperature below red heat as the heating medium. Such a boiler or heater would enable us to settle many questions regarding the transfer of heat which are now in controversy.

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THE AUTHOR. Fig. 23 represents some work done after hearing Professor Fessenden's criticism that the lines giving the values of the coefficients B and m in Fig. 13 cannot be extended to flue diameters larger than 2 in. In Fig. 23 the values are plotted against each other on a logarithmic scale instead of linearly as in Fig. 13, and points are added for the Heine and Nicolson boilers. Professor Fessenden showed that the coefficients for these boilers did not harmonize with the plot of Fig. 13, nor with his values of U plotted in Fig. 21. It will be seen that the plotting used in Fig. 23, besides bringing the points for the small-diameter flues more nearly into line, brings the lines when extended very close to the points for the larger flues. The lines in Fig. 13 give reasonably accurate results for flues up to 2 in., but those in Fig. 23 are recommended for general use.

I believe that a formula of this sort can be applied to the condition that Mr. Ostgren speaks of in air flowing through the inner flue, if it is possible to get the mean temperature of the flue wall.

In reply to Mr. Barkley, I should like to point out that the formula proposed covers all of the physical factors involved in heat transfer and is still of a form sufficiently simple for practical use. I must take issue with him as to the values of the specific heat of gases at high temperatures. Reference to the Smithsonian Tables will show the problem has been solved for all practical purposes, and that calculations based on the specific heat will be more accurate than any heat-balance results.

I would like to point out that the paper refers to the point that was mentioned by Dr. Jacobus in regard to the loss of draft, viz., that by decreasing the flue diameter the rate of heat transfer can be increased, but that this will be done at the expense of loss of energy in forcing the gas through the flue. The loss of draft — loss of head — in passing through the flue is the price that must be paid for increased heat transfer, and if a formula similar to that used for loss of temperature can be obtained to take care of loss of head, it will be possible to figure out exactly what has to be paid for a given rate of heat transfer, and to calculate for any kind of a boiler with greater certainty.

I would add that two of the important series of tests mentioned in the paper were carried out by the Babcock & Wilcox Company, under the direction of Dr. Jacobus, who courteously placed them at my disposition.

Professor Kent's criticism is mainly based on a comparison of the Fry-Hedrick-Fessenden formula with his own straight-line formula for

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boiler efficiency. I am afraid that I cannot agree with him that lack of agreement between the two proves that the formula proposed in the paper is inaccurate. Professor Kent assumes for his formula that the heat transmitted varies as the square of the temperature difference and is independent of the flue diameter and of the velocity of the gases. This assumption begs the whole question. It dates

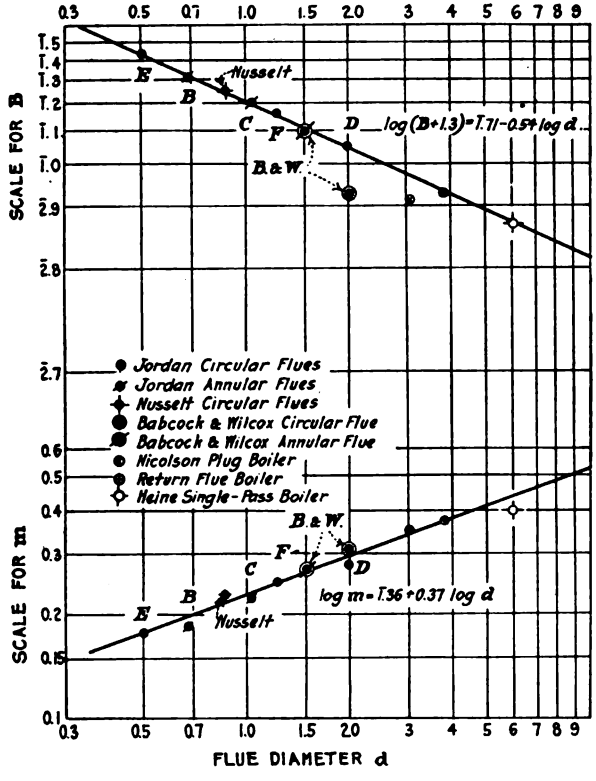

FIG. 23 RELATION BETWEEN FLUE DIAMETER AND COEFFICIENTS B AND m IN THE EQUATION LOG $M = B - m$ LOG W/p

from Rankine's time, and with the experimental data now available can easily be shown to be incorrect. Any one of the series of tests analyzed in the present paper shows the large influence exerted by the gas velocity on the rate of heat transmission, while the effect of flue diameter is shown by a number of the experiments. In the Pennsylvania Railroad locomotive tests analyzed in Fig. 17 the difference between $1\frac{3}{4}$-in. and 2-in. flues is reflected in the boiler efficiency.

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The Babcock and Wilcox experiments show the difference between a circular flue 2 in. in diameter and an annular flue with an effective diameter of about 1.5 in.; while the Fessenden and Haney experiments show the difference between flues 1.816 in. and 0.816 in. in diameter. Further, the principle that a reduction in flue diameter increases the rate of heat transfer is recognized in modern boiler design, as, for example, in waste-heat boilers, where narrow gas passages are used in order to secure high absorptive efficiency with low gas temperatures.

Professor Kent's straight-line formula may serve to give an idea of the efficiency of an average boiler under normal operating conditions, but it is useless in a study of the effect of variations in the section of the gas passages and in the rate of flow of the gases, questions which are of great practical importance.

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No. 1612

A STUDY OF SURFACE RESISTANCE WITH GLASS AS THE TRANSMISSION MEDIUM[1]

By H. R. Hammond[2] and C. W. Holmberg,[3] Brooklyn, N. Y.
Non-Members

In heat-transmission work the majority of coefficients used at present are combined coefficients, that is, no attempt is made at discriminating between the conduction of the material itself and the conductions of the two air spaces which exist adjacent to it. Consequently there are no standards by which surface resistance may be obtained.

The authors describe an investigation carried out in the thermal testing plant of The Pennsylvania State College and give a formula by which the combined transmission coefficients, as well as the conduction values for the glass inside air surface and outside air surface, may be calculated.

The results of the tests made demonstrate that the greater part of the air-layer resistance occurs at the outside and within the first half inch of the surface; and that whenever glass or any other good material is used as the transmission medium, the resistances of the inside and outside air surfaces play the major part in determining the combined transmission coefficient.

IN the study of heat transmission the determinations of the thermal resistances of materials have been obtained in a more or less vague manner. At present the majority of coefficients used are combined coefficients; that is, no attempt is made at discriminating between the conduction of the material itself and the conductions of the two air spaces which exist adjacent to it. Consequently there are no standards by which surface resistance may be obtained. A method has been used by which the temperatures of the air, both outside and inside, were measured at a distance of 1 in. from the surface; but this has never been verified.

[1] This paper is based upon data gathered in The Pennsylvania State College Engineering Experiment Station, and which will appear in its Bulletin No. 24.

[2] Died November 28, 1917.

[3] 354 Senator St.

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers. Awarded Student Prize for the year 1917.

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2 In an attempt to obtain some data on the subject of surface resistance with glass as the transmission medium, this paper will deal with the following points:

a A study of the temperature gradients under various temperature differences between the inside and outside of the box used in the experiments

b The relative values of conduction for the glass and for the air surfaces

c The variation of the conduction values under the various temperature differences between the inside and the outside of the box.

THEORY

3 Heat may be transmitted from one side of a wall to the other in three ways: by radiation, by convection, and by conduction. In this paper, however, the radiation and convection factors are not dealt with, and the formulæ have to do only with conduction.

4 For total heat transmitted, we may write:

$$Q = k\,A\,(\Delta T) \qquad [1]$$

where Q = total B.t.u. transmitted per hour
k = transmission in B.t.u. per hour per sq. ft. per deg. difference in temperature
A = area of the surface in sq. ft.
(ΔT) = temperature difference, deg. fahr.

5 The value of k depends upon several factors: the surfaces, the thickness and kind of material, air spaces, absolute temperature, temperature difference, and condition of air at the surfaces. The combined transmission coefficient of a compound wall is determined from the sum of the reciprocals of the various conduction coefficients, as follows:

$$k = \frac{1}{\frac{1}{C_1} + \frac{x_2}{C_2} + \frac{x_3}{C_3} \cdots\cdots \frac{x_n}{C_n} + \frac{1}{C_{n+1}}} \qquad [2]$$

where C_1 = conduction of inside air surface in B.t.u. per hr. per sq. ft. per deg. difference in temperature
$C_2, C_3, \ldots C_n$ = conduction of material per hr. per unit thickness per sq. ft. per deg. difference in temperature
C_{n+1} = conduction of outside air surface in B.t.u. per hr. per sq. ft. per deg. difference in temperature
$x_2, x_3, \ldots x_n$ = thickness of material in inches.

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PROCEDURE

6 The experiments were carried on in the thermal testing plant of The Pennsylvania State College, which consists of a room 17x17x 10 ft., well insulated with corkboard and kept at a constant temperature by means of brine coils placed around the wall. Bulletin No. 9, Vol. 1, published by The Pennsylvania State College Experiment Station, contains illustrations and a complete description of this plant.

7 The experiments were made with a corkboard box (Fig. 1) 5 ft. x 5 ft. x 5 ft. 1 in. in outside dimensions and having a mean

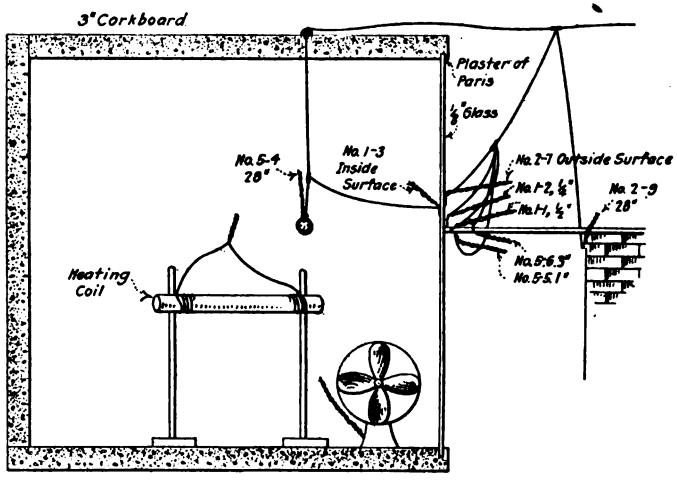

FIG. 1 APPARATUS FOR DETERMINING TEMPERATURE GRADIENT

surface area of 141 sq. ft. The temperatures were recorded by platinum-resistance thermometers made by the Leeds & Northrup Co. and specially designed for this plant. Carefully calibrated voltmeters and ammeters were used to measure the heat input to the box.

8 Before proceeding with the tests the resistance thermometers and the box were carefully calibrated. The thermometers were calibrated by comparison with a standard mercury thermometer reading to 0.2 deg. and estimated to 0.01 deg. The thermometers were placed in a small box to protect them from any air currents that might affect the readings. The readings on the mercury thermometer were taken through a telescope in order that they might be estimated

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more accurately and not be affected by heat radiation from the person taking them. The resistance-thermometer readings were indicated by the usual Wheatstone bridge as supplied by Leeds & Northrup Co. Readings were taken of the various thermometers every ten minutes, and after a series of tests under different temperatures, the calibration curves were plotted.

9 In calibrating the corkboard box for different ranges of temperatures from inside to outside, a thermometer was suspended midway between the top and bottom and 10 in. from the inside surface, and another placed outside in the room. The room was kept at a

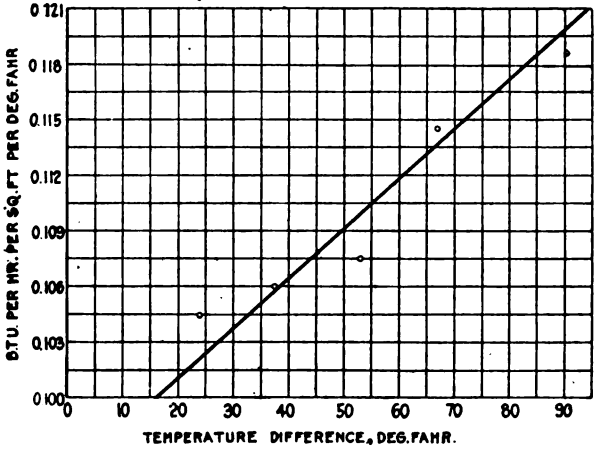

FIG. 2 TRANSMISSION OF CORKBOARD BOX

constant temperature by means of brine circulating through coils around the room. Inside the box was placed a fan for the purpose of circulating the air and thus keeping the box at a uniform temperature throughout. The desired temperature was obtained by means of an electric heating coil placed in the center of the box. During the tests, readings were taken every ten minutes of the temperature inside and outside the box and of the voltage and amperage input. When the readings became constant they were considered acceptable and the rate of transmission in B.t.u. per hour per square foot was calculated from the formula

$$k = \frac{3.412 \times A \times V}{\text{mean area of box surface} \times \Delta T} \quad \ldots\ldots\ldots\ldots [3]$$

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where A = ammeter reading in amperes
V = voltmeter reading in volts
3.412 = heat equivalent of watts per hour
ΔT = temperature difference.

The calibration curve for the various temperature differences is plotted in Fig. 2.

10 After calibration the removable corkboard side was taken off and replaced by a glass plate $\frac{1}{8}$ in. thick. Thermometers were placed at distances of $\frac{1}{4}$ in., $\frac{1}{2}$ in., 1 in., 3 in., and 28 in. from the inside surface, also on the inside and outside surfaces and 28 in. from the outside surface. Tests were made in the same manner as when the box was calibrated.

11 All tests were run until the respective thermometers had maintained constant readings for some time. The arrangement of thermometers afforded ample opportunity to determine the temperature gradients.

12 Owing to the few available thermometers, it was not possible to run tests for inside and outside gradients simultaneously. Consequently the thermometers were rearranged as follows for the outside gradient tests: 28 in. inside, inside surface, outside surface, and $\frac{1}{4}$ in., $\frac{1}{2}$ in., 1 in., 3 in., and 28 in. outside. All tests so far had been run with circulating air inside and still air outside. During this set-up, however, air currents were induced by a motor-driven fan which forced air through a narrow slit-like aperture 1 in. wide and discharged across the surface of the glass with mean velocities at the thermometer of 800 and 1100 ft. per min. for two tests, respectively. Results of the outside gradient tests are plotted in Fig. 3, herewith shown. Two curves obtained under conditions of temperature and temperature range similar to those of the inside gradient tests were plotted in Fig. 4 together with the inside gradients as though they were obtained simultaneously.

13 On account of breakage, the plain glass window was now replaced by a four-pane window sash. Thermometers were placed at 28 in. inside, the inside surface, the outside surface and 28 in. outside the window. Tests were now run in the same manner as the preceding ones, especial care being taken to keep constant voltage and amperage in the heating coil, since these tests were primarily transmission tests. The combined transmission coefficient (k_1) of the window glass was calculated from the following formula:

$$k_1 = \frac{3.412\,VA - k_2 S_1\,(\Delta T) - 0.8\,S_3\,(\Delta T)}{S_2 \times (\Delta T)} \quad \ldots\ldots\ldots [4]$$

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where V = volts in heating coil + volts in circulating fan
A = amperes in heating coil + amperes in circulating fan
S_1 = mean area of surface of 5 sides of corkboard box, sq. ft.
S_2 = mean area of surface of window panes, sq. ft.
S_3 = mean area of surface of sash (wood), sq. ft.
(ΔT) = temperature difference (inside − outside), deg. fahr.
0.8 = coefficient of transmission of wood
k_2 = coefficient of transmission of corkboard.

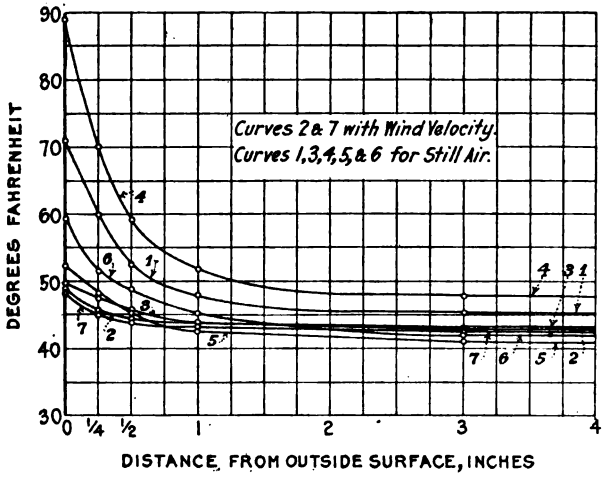

FIG. 3 OUTSIDE TEMPERATURE GRADIENTS

The coefficient k_1 was calculated for various temperature differences as shown above and the results plotted in Fig. 5.

14 The conductions of the two air surfaces and the glass were determined similarly to the combined transmission coefficient, save that the value of (ΔT) in the denominator varied as the temperature differences of the various layers of material concerned. These curves are likewise plotted in Fig. 5 for the purpose of comparison.

SAMPLE CALCULATIONS

15 When $(\Delta T) = 23.15$ deg. fahr.,

k_1 (combined transmission coefficient of glass) =

$$\frac{(3.412 \times 49.5 \times 4.51) - (0.8 \times 0.58 \times 23.15) - (117.3 \times 23.15)}{21.4 \times 23.15} =$$

$$\frac{770 - 10.75 - 277}{495} = \frac{482.25}{495} = 0.974$$

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$$C_2 = \text{conduction of glass} = \frac{482.25}{21.4 \times 1.26} = 17.88$$

$$C_1 = \text{conduction of inside air surface} = \frac{482.25}{21.4 \times 7.93} = 2.84$$

$$C_{n+1} = \text{conduction of outside air surface} = \frac{482.25}{21.4 \times 13.96} = 1.615$$

DISCUSSION OF RESULTS

16 When plotted, all of the temperature gradients from the surface proved to be smooth curves. This result amply justified the method of testing which was employed during the entire series of

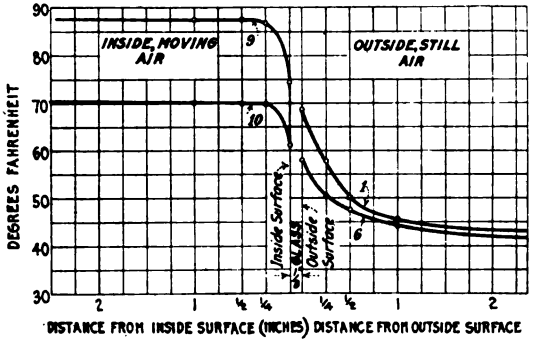

FIG. 4 COMBINED INSIDE AND OUTSIDE GRADIENT

tests, both gradient and transmission. In this method of testing the authors continued the test until constant readings in the respective thermometers had been maintained for some time. The time elapsing before this condition was obtained varied between two and eight hours.

17 The inside gradients bent down sharply within the first quarter of an inch. Then the curves grew flatter, until at a distance of ½ in. from the surface of the glass the curves became constant. The outside gradients were more gradual in character, the major part of the drop occurring in the first two inches from the glass for still-air conditions, while the gradients obtained under moving air were considerably flattened and reached a nearly constant value within the first inch.

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18 These results would indicate that the circulating air inside cut down the air resistance film at the surface of the glass and thus increased the conduction of the air layer.

19 Under still-air conditions the outside surface resistance was considerably greater than with moving air. This was undoubtedly due to the fact that much heat was carried away by convection.

20 These tests indicate that the resistance is greatest very close to the surface of the glass and that when performing experiments in heat transmission it is best to place the outside thermometer not less than 2 in. from the surface under still-air conditions; and not less than 1 in. under moving-air conditions when the air velocity is greater than 800 ft. per min.

21 The combined transmission coefficients and the conduction values for the glass inside air surface and outside air surface were calculated by formula [4] and are as follows:

	Temperature range, deg. fahr.			
	23.15	40.37	54.45	73.52
Combined transmission	0.974	1.079	1.159	1.165
Conduction of glass	17.880	18.050	19.800	19.890
Conduction of inside air surface	2.840	3.315	3.650	3.560
Conduction of outside air surface	1.615	1.750	1.850	1.900

22 The combined-coefficient values check up fairly well with the values 0.96 (dry glass) and 1.1 (wet glass) for a single window $\frac{1}{8}$ in. thick, given in Greene's Elements of Heating and Ventilation. Moreover, they show that the transmission varies linearly with the temperature differences, as the curve plotted in Fig. 5 will demonstrate.

23 The conduction values for the glass under the same temperature differences show that they also varied in the same way as the combined-transmission values.

24 The conduction values for the air surfaces confirm the results of the gradients, in that the resistance of the outside air surface is shown to be considerably less than that of the inside air surface. Curves of the surface resistance plotted to an enlarged scale in Fig. 6 show that the conduction of the surfaces is greatest at points where the temperature ranges vary from 65 deg. to 75 deg. This seems to

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indicate that there is a saturation point at which the transmission through the air layer cannot be increased. The writers believe that it would be highly desirable that further investigations be undertaken in order to check up this point.

25 Fig. 5 shows the relationship between the conductions of the air surfaces and the glass. It can be seen that the resistance of the glass is very slight as compared with that of the air surfaces. This proves that in figuring transmission through glass the resistance of the air layers at the given conditions will be the primary factors, since from the figure it is shown that they form the bulk of the resistance which goes to make up the combined transmission factor. In connection with this point it is interesting to note the investigations

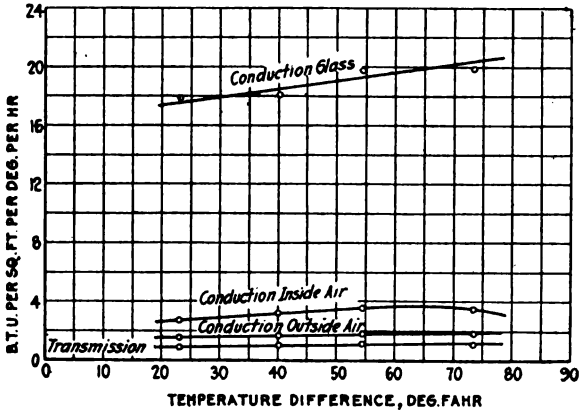

FIG. 5 CONDUCTIONS THROUGH AIR SURFACES AND GLASS

carried on by Professor Moyer in The Pennsylvania State College Thermal Testing Plant, and described in the *A. S. R. E. Journal*, Vol. 2, No. 3. Professor Moyer's results indicated that the influence of air velocity on transmission through glass caused the transmission coefficient to vary from a value of 1.263 at zero velocity to 4.207 at a velocity of 1200 ft. per min. This illustration further proves the extreme importance of the air surface resistance on the combined-transmission factor.

26 Consequently, the subject of air resistance seems worthy of careful investigation as to its behavior under varied conditions. The writers in suggesting further investigation along this line would say that they consider thermocouples preferable to resistance thermometers. Resistance thermometers, on account of their appreciable

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size and consequent susceptibility to radiation, make very accurate surface readings impossible, while the fine-point contact of the thermocouple makes it very desirable in this connection. Delay in obtaining thermocouples caused the writers to use resistance thermometers in these tests.

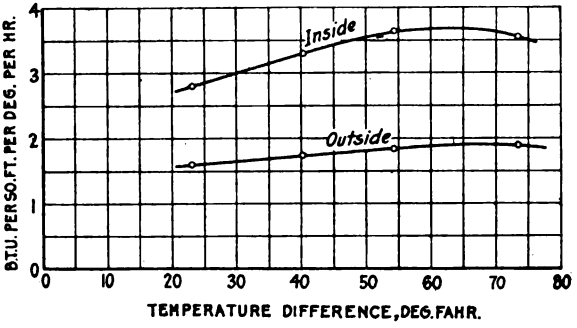

FIG. 6 CONDUCTION THROUGH AIR SURFACES

CONCLUSIONS

27 A summary of the more important results obtained in the tests is as follows:

a The gradient tests demonstrate that the greater part of the air-layer resistance occurs at the outside and within the first half inch of the surface

b Whenever glass or any other good conductor is used as the transmission medium, the resistances of the inside and outside air surfaces play the major part in determining the combined transmission coefficient

c The tests show that the transmission through glass and through corkboard with temperature differences ranging from 20 deg. to 80 deg. varies linearly with these temperature differences.

28 The writers wish to acknowledge much valuable assistance received from Prof. A. J. Wood and Prof. R. B. Fehr of The Pennsylvania State College. They are also indebted to The Engineering Experiment Station of The Pennsylvania State College for some of the data used.

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APPENDIX

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Experiments on Cold Storage Insulation, by K. Hencky. Zeitschrift für die Gesamte Kälte-Industrie, August–September, 1915. Abstracted in A.S.R.E. Journal, Vol. 2, No. 3.

The Testing of Thermal Insulators, by H. C. Dickinson and M. S. Van Dusen. A.S.R.E. Journal, Vol. 3, No. 2.

Determining Heat Transmission of Compound Walls, with Tests on Insulated Steel Car Sections, by A. J. Wood. A.S.R.E. Journal, Vol. 3, No. 4.

DISCUSSION

A. J. Wood (written). The authors clearly distinguish between transmission through the glass and the surface transmission. This is important. For the most part, tables appear giving *conduction* only. To apply these values to the usual practical problems, we should also know the values for the surface effect The table in Par. 21 and Fig. 5 bring out the importance of separating the two. They also show the effect of temperature range on heat transmission, which is found to influence the conduction to a considerable degree.

On December 4, Prof. R. B. Fehr and the writer discussed in detail, before the American Society of Refrigerating Engineers, the results of recent work at the thermal testing plant of The Pennsylvania State College.[1] Among other constants given, we stated that under usual temperature conditions and for "still" air, the total surface transmission for *both sides* of glass, corkboard and building paper was found to average about 22 B.t.u. per 24 hr. per sq. ft. per degree difference, which value is approximately 0.9 B.t.u. per hr. per sq. ft. per degree difference. Pending the results of more extended tests, this value is believed to be a safe one for general practice.

In Vol. 24 of Transactions[2] Dr. William Kent quotes the value of B.t.u. transmitted per hour per sq. ft. of surface per deg. fahr. difference of temperature for a single window as 1.03. I understand this to be the *total* transmission (including the two surfaces), and this

[1] For complete paper, see A.S.R.E. Journal, March 1918.

[2] Trans.Am.Soc.M.E., vol. 24, p. 284. See also Kent's Mechanical Engineers' Pocket-Book, 9th ed., p. 583.

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value is in substantial agreement with our value of 0.90 noted above. Other determined values for the surface effect are noted in our discussion before the American Society of Refrigerating Engineers.

L. B. McMillan (written). The conclusions which the authors have reached regarding the importance of the air-film effect are in accordance with the theory on the subject and check closely with the results by other investigators. However, their work shows more forcibly than ever the need for full and complete data on the subject of surface resistances.

Considerable work has already been done on this subject — much more than would appear at first thought. For example, it has been nearly one hundred years since Péclet made his classical experiments, determining radiation coefficients for a number of materials, and these, in connection with convection coefficients, indicate the rate of flow from the surface or conversely the surface resistance. One reason why there seems to be such a scarcity of data on surface resistances is that this relationship of surface resistance to surface transmission is very generally overlooked.

Dulong builded on the work of Péclet and worked out equations for the radiation coefficients at various temperatures. These are given in Kent's Pocket-Book, together with tables prepared by Box which facilitate the finding of the coefficient at any temperature. This would go a long way toward filling the need except for the fact that Péclet's coefficients have been found to be very considerably too low. For example, Paulding (*Stevens Indicator*, vol. 19, p. 393) has shown that Péclet's coefficient of 0.64 for iron is much too low, and that modern tests prove that this coefficient should be about 0.87.

Péclet's results are therefore of interest mainly for their historical importance and because of the thoroughness with which he attacked the problem, even at that early date.

Fig. 7 shows results of some of the modern investigations[1] as compared with Péclet's results, and illustrates how well the modern tests agree, even though made by widely different methods. For example, the tests by Barrus, Brill, Jacobus, Eberle and that labeled

[1] Geo. M. Brill, Trans.Am.Soc.M.E., vol. 16, p. 827. Geo. H. Barrus, Trans. Am.Soc.M.E., vol. 23, p. 791. C. L. Norton, Trans.Am.Soc.M.E., vol. 19, p. 729. Prof. D. S. Jacobus, Stevens Indicator, vol. xix, p. 12; Stevens Indicator, vol. xix, p. 388. Chr. Eberle, Verein Deutscher Ing., Mit. über Forschungsarbeiten, Heft 78. Thomas Box, Practical Treatise on Heat, and Kent's Pocket-Book. L. B. McMillan, Trans.Am.Soc.M.E., vol. 37, p. 921.

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"Stevens Indicator" were condensation tests, while those by the writer were by the electrical method, and yet the results are in very close agreement, while the curve showing Péclet's results falls far lower.

The data referred to are not presented as being directly comparable with the results presented by the authors of the paper under discussion, as these do not refer to glass surfaces. However, the data

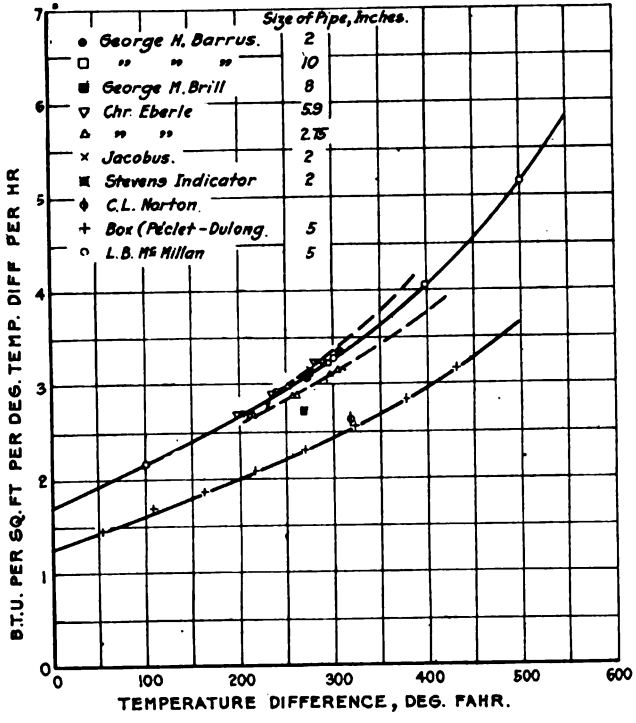

FIG. 7 COMPARISON OF RESULTS OF VARIOUS INVESTIGATORS ON HEAT TRANSMISSION FROM BARE PIPE SURFACES TO AIR

are of similar nature, as the results shown in the figure represent surface conduction for cylindrical surfaces where the character of surface is that of an ordinary steel pipe.

In pointing out the difference between Péclet's results and those of modern tests this is not intended as a criticism of Péclet's work, for considering the time at which it was done it was a great achievement; but now, with infinitely better facilities for research, we should repeat his work on even a larger scale than that which he attempted, and in

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addition to having the coefficients for various surfaces and laws showing how they vary with temperature, we should have also the laws showing the effect of wind velocity, humidity, etc.

This, however, would be a very large undertaking and could not be handled by one individual or concern, though some of the larger manufacturers of insulating materials have well-equipped laboratories and would be glad to coöperate in such a movement; The Bureau of Standards has done much creditable work along this line and will probably do more, but great results can be accomplished in the university laboratories and experiment stations as is shown by the paper under discussion.

The foregoing may appear at first thought to be rather much of an academic discussion, but it decidedly is not, and a few illustrations will show how useful these coefficients are in the solution of every-day engineering problems.

For example, many data regarding conductivities of materials are now available, and with complete information as to surface resistances the calculation of heat-flow problems will be much less of a bugbear than it has been in the past.

Furthermore, the only effect which wind velocity can have upon the heat losses from a surface is to decrease the surface resistance, therefore this effect can easily be isolated and determined. The same is true of air humidity, except where the material is affected by moisture.

As pointed out by the authors, the surface resistance is the greater part of the resistance to heat flow through good conductors of heat, and for the accurate solution of problems of this kind accurate data on surface resistances must be had.

Furthermore, it is often desirable to estimate beforehand the temperature of the surface of a stack or furnace when the thickness and character of the walls and the temperature of the inside of the furnace are known.

As an illustration of the use of surface resistances in the solution of an actual problem, a 4-in. brick wall may be considered, the conductivity of the brick being taken as 6 and surface conduction as 2. This will make the rate of heat flow $= 1/[1/2 + 4/6 + 1/2] = 1/1.67 = 0.6$ B.t.u. per sq. ft. per deg. temperature difference per hour. It is to be noted that the combined resistances of the two surfaces are greater than the resistance of the four inches of brick.

If in place of the brick the wall was a 4-in. thickness of a good insulating material having a conductivity of 0.5, the rate of heat flow

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would then be equal to $1/[1/2 + 4/0.5 + 1/2] = 1/9 = 0.11$ B.t.u. per sq. ft. per deg. temperature difference per hour. In this case the resistance of the material is eight times the combined resistances of the two surfaces.

Therefore, while these things can be done with a considerable degree of accuracy, even with the data now at hand, it would be quite an advance to have full and complete information. This is particularly true regarding the good conductors of heat, for the data now available serve very well in insulation problems where air resistance is the small part of the total resistance.

Returning again to the paper under discussion: The authors state under Conclusions that the greater resistance is at the outside surface of the glass, and attention is called to the fact that this refers to the conditions of test and is not made as a general statement, as the resistance of the inside surface during these tests was greatly dissipated by the air circulation.

Also, it would seem from former investigations that the curves in Fig. 6 should bend upward at the higher temperatures instead of downward. However, a wider temperature range might be necessary to make this change considerable, and for the given range the figures are probably very nearly correct.

In conclusion, I wish to repeat that I believe it would be well worth the trouble to investigate through a wide range of conditions the surface resistances of various materials.

E. A. FESSENDEN thought the temperature-gradient curves given n the paper were important, and it seemed to him that it might very well be emphasized in this connection that, where total transmission was being sought, the thermometers for measuring temperature should be placed at a considerable distance from the surface to get on to the horizontal part of the curves and away from the sloping gradient — possibly ten inches or a foot or more away, but at least not near the surface.

ARTHUR K. HOLMES called attention to the fact that in Fig. 5 the conduction of heat through glass seemed to vary between 18 and 22 B.t.u., while in Par. 22 it was stated that "the combined-coefficient values check up thoroughly well with the values 0.96 (dry glass) and 1.1 (wet glass) for a single window," or about one-twentieth as large.

L. B. MCMILLAN said that in one case where the temperature went up to 500 deg. and the thermometers were placed at least 5 ft.

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away, unless they were shielded by a sheet of paper between them and the heated pipe, they would still, by radiation from the pipe, show a higher temperature than the room air. He therefore thought Professor Fessenden was quite right in saying that it was the temperature of the room air that should be taken as the lower temperature.

C. W. HOLMBERG. Mr. Holmes has mentioned that the conduction values given for glass seem to be about 15 to 20 times those that were spoken of in regard to the combined-coefficient values as checking up fairly well with the values 0.96 and 1.1 for a single window. It is to be noticed, however, that in this connection it was said that, "Moreover, they [these values] show that the transmission varies linearly with the temperature differences," which indicates that we were speaking of transmission values. The transmission value takes into account not only the conduction of the glass but the two surfaces, and it is the two surface values which so reduce the amount of heat that will go through there as to give that decreased value.

The glass itself is a very good conductor, and if taken by itself, without any surface resistance, there is very little resistance to heat going through; but with the two air resistances taken in conjunction with it, it gives the bottom curve on Fig. 5, marked "Transmission," which represents the value spoken of in Par. 22 and referred to by Mr. Holmes.

Lest misconception should arise regarding the conduction curves plotted in Fig. 5, I would say that the abscissæ represent total temperature differences (inside to outside of glass). As indicated in the table in Par. 21 and in Par. 25, the conduction curves are plotted merely for the purpose of comparison with the total transmission curve.

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No. 1613

APPARATUS FOR COOLING, DRYING AND PURIFYING AIR

By W. J. Baldwin, New York, N. Y.
Member of the Society

This paper describes an apparatus for purifying air and regulating its temperature and humidity by mechanical means. In principle it consists of the use of a cold spray for the purification process, after which the excess moisture, together with particles of dust, excess CO_2, etc., are separated from the air by centrifugal action. In one of its original forms the device was applied to the porthole of a ship for the purpose of drawing into the cabin large quantities of air but excluding rain or spray. It has also been used to remove CO_2 from vitiated air, as in the compartments of a submarine, and for removing particles of dust from the gases of combustion in a chimney.

THE necessity for removing dust and other impurities from the air needs no amplification from me, as we all recognize the advantages of pure air and nearly all strive in every way to obtain it.

2 The ordinary meaning of the term pure air, however, should be amplified, and when it appears in a contract it should mean more than that the air should not be fouled by the human breath and by exhalations from the human body. The engineer must not be content when making an examination within an enclosed structure simply to report that the air is maintained at some common standard of purity or contamination, expressed by the number of times the CO_2 within the room is in excess of the standard, good or bad, found to exist outside the enclosure. Such a standard gives only an approximate idea of the condition of the air within the enclosed space, and it is the roughest approximation under the common acceptation of the term.

3 Presumably there is no pure air near the surface of the ground, nor in the atmosphere of cities. The best we have exists at the tops of mountains, or on the ocean, but even this we are unable to standardize.

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers.

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4 Air with about two parts of CO_2 in 10,000 is considered good, no matter where we find it; but in cities where much coal is burned the proportion is higher, and may rise to as high as 10 parts of CO_2 in 10,000. An increase from 2 to 4 parts in 10,000 for enclosed spaces above the outside conditions has been considered good, even for schools and hospitals, and very good for workshops.

5 These conditions, however, do not comprise the whole problem. Further effort should be directed toward drying air by some simple mechanical process. In attempting to free air from an excess of humidity, which is often as much of an impurity as are the other forms of contamination, I have the following data to offer:

6 About two years ago I worked to perfect an apparatus that could be put in the porthole or the dead light of a ship and would exclude the rain or spray, while freely admitting large quantities of air to the cabin of the ship, without admitting the water. This led to freeing the air of an excess of humidity.[1]

7 The experiments conducted with the preliminary apparatus for excluding rain or spray while freely admitting the air as in the case of a ship rolling heavily at sea, suggested the possibility of removing the excess of humidity in the air, particularly with a view to admitting air to the radio room of a ship, and not only exclude the rain and spray but also regulate the humidity, so as to keep the air at *some common standard of saturation* as far as humidity was concerned. The purpose was to overcome a difficulty with the attuning apparatus of the receiving and sending instruments, either at sea or in the higher atmosphere.

8 This led to the design of an apparatus for a radio room on the lines already set forth, that would admit air not only separated from rain, salt spray and spume, but that would also condition or regulate the humidity within the room by keeping it at a common standard of humidity, regardless of the outside changes.

9 Cold water in the spray form will do this, provided the spray can be gotten rid of after it has combined with the excess of humidity (steam in the air) and then separated from the air by some practicable form of apparatus that is simple and clean, and that occupies small space.

10 While "a shower of rain will clear the atmosphere," the elements of nature have all outdoors in which to set up the apparatus for such a result. The cabin of a ship or a radio cabinet is infinitely

[1] An account of this apparatus, with illustrations, appeared in the Proceedings of the American Society of Heating and Ventilating Engineers, January 1917.

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small in comparison with all outdoors, yet a similar result can be achieved in a space as small as a cabin or radio cabinet.

11 To accomplish this I used a cold-water spray apparatus

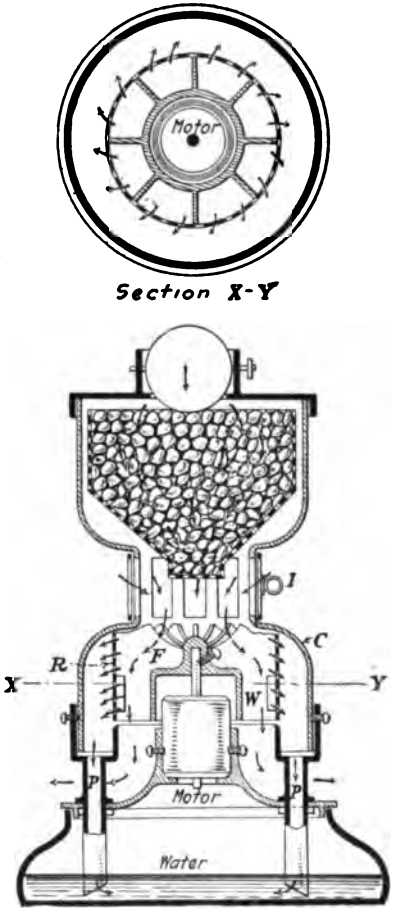

FIG. 1 APPARATUS FOR DRYING AND COOLING THE AIR OF A ROOM AND ILLUSTRATING ALSO THE PRINCIPLE USED IN VARIOUS OTHER FORMS OF THE DEVICE

similar to one I had designed two years earlier for the purpose of precipitating the CO_2 when found in great excess in a confined space, as in the hold of a submarine, when forced to stay a long time under water.

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12 In this machine a spray of potash water was used in connection with a mechanical dust precipitator for the purpose of seizing on the carbonic acid in the air and throwing it down, so as to eliminate the CO_2 at the dust and water discharge of the apparatus.

13 It was proposed to put the apparatus in a bulkhead; the discharge side of the apparatus coming into the air of the living quarters, the air freed of its CO_2 being forced backward again into the chamber of greatest vitiation, thus forming a cycle.

14 In the general experiments it was found that a prepared spray of chemical liquid or even cold water not only seized on the dust but on other gases in the air, with which the chemical in the spray

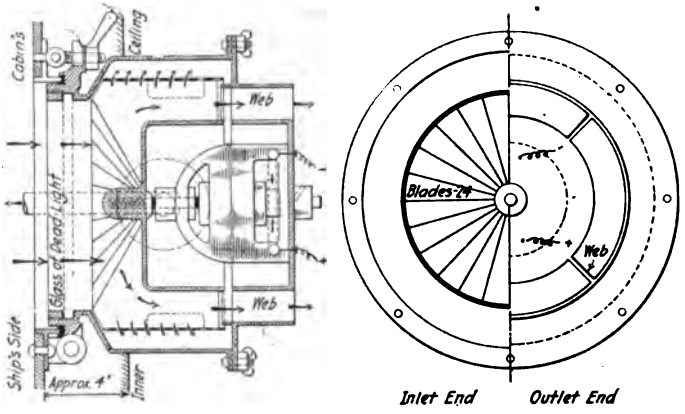

FIG. 2 APPARATUS ATTACHED TO PORTHOLE OF SHIP FOR ADMITTING AIR AND EXCLUDING RAIN OR SPRAY

would combine, and that a pure-water spray turned into the apparatus would keep the humidity of the air constant by suitable regulation of the temperature of the water spray. In a room at 90 deg. fahr. and a humidity of almost 90 per cent we could drop the humidity to 45 per cent by reducing the temperature of the spray to 70 deg. fahr.

15 A simple form of the apparatus arranged for cooling a room is shown in Fig. 1. The apparatus from the inlet to the line *X-Y* is an ordinary fan or blower *F*, and the downward extensions of the fan blades or wings *W* are necessary to accelerate the rotary motion of the air.

16 The rotor *R* is a rotating hoop of permeable metal, against the inner side of which the air is thrown with all its impurities. If the heavy particles in the air, such as dust, mud or particles of water,

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strike into the perforations of the hoop, they pass through into a quiet space formed by the outer case C. Or, if they strike on the solid part of the hoop, they are rubbed through the nearest holes by the forward movement of the air. They then pass into the quiet space C, drop down within it, and escape by the pipe or pipes P into the tank.

17 The air does not escape with the heavy particles, as might appear at first, for the lower ends of the pipe legs are sealed by the water in the tank. The tank may be of any shape, or there may be no tank, the separated particles going to a waste pipe.

18 The greater the velocity of the rotor R the more efficient is the apparatus. A speed of 5000 ft. per min. is very practicable, but

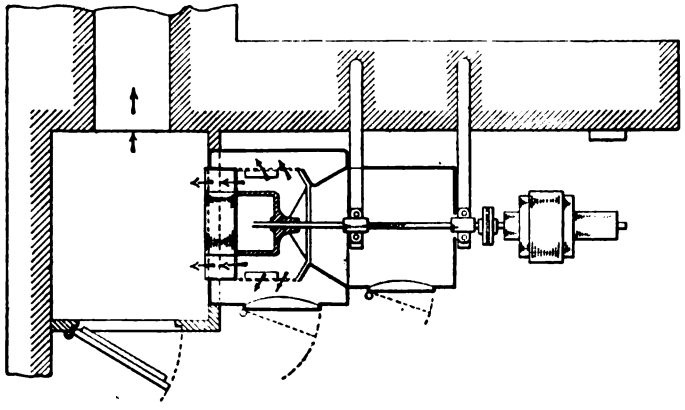

FIG. 3 APPLICATION OF APPARATUS TO BASE OF CHIMNEY FOR REMOVING PARTICLES OF DUST FROM GASES OF COMBUSTION

10,000 is not excessive, either from the point of bursting or for any other reason.

19 The fan gives the same static pressure as any other centrifugal blower of equal diameter and speed and requires only equal power for equal work, and the power required for separation and friction is considerably under 25 per cent of the blower power required to move the air.

20 The device as described above illustrates the principle of the various types of apparatus, whether used for taking the dust from the air, the CO_2 from a chimney or an enclosed space, the excess of humidity from the air, throwing down fog, cooling and moving air, etc. It will be noted that the ice in the upper tank serves both as a

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cooling medium and for the supply of cold water, broken into spray by the rapid motion of the fan, for the purification of the air.

21 In Fig. 2 is shown a type of the apparatus as developed for use in the porthole of a ship, and in Fig. 3, a horizontal design for the removal of dust particles from the air of buildings, the apparatus shown being the one used in the Lederle Antitoxin Laboratories at Pearl River, New York.

In presenting his paper the author gave brief particulars of views projected on the screen showing various forms of the apparatus and uses to which it had been applied. The largest apparatus in use handled from 16,000 to 20,000 cu. ft. of air per minute. It was a dry apparatus and was used in the Flatbush Gas Company's plant on one of their boilers, and had been in use for over a year. It removed 96 per cent of the dust that would ordinarily escape up the chimney, 46 per cent of which was so fine that it would go through a sieve of 200 mesh.

It was desirable not to use water when handling chimney gases. If water was used acids would be condensed and the flues would give out in a very short time, especially if salt water was employed. In New York and in Brooklyn, where a salt-water spray running over an apron was used, it attacked the iron so rapidly that it disappeared in a few months.

In portland-cement mills the apparatus when operated dry would recover 83 per cent of the cement escaping from the top of the chimney and floating out over the country, and when water was turned on, 100 per cent.

The apparatus could also be used for "throwing down" and removing by-products from escaping gases from mechanical plants and gas-producing apparatus, etc.

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No. 1614

RECENT DEVELOPMENTS IN BALANCING APPARATUS

By N. W. Akimoff, Philadelphia, Pa.
Member of the Society

Improvements have been made by the author upon the balancing machine described by him in a paper presented before the Society in 1916. Also a complete revision of the usual method for securing static balance in a body used as a step in the process of determining its dynamic balance. Two formulæ are given to estimate numerically the lack of precision in ordinary methods for obtaining such static balance.

The author now uses a clamp attached to the body to be balanced, whereby a known centrifugal force is introduced when the body is rotated, for the purpose of neutralizing the static or dynamic unbalance of the body. By suitably constraining the motion of the rotating body, either the static or dynamic unbalance, or the combination of both may be accurately measured through the adjustment of the clamp.

SINCE my paper on the subject of Dynamic Balance[1] was presented, certain improvements have been made by me in the machine there described; also an entirely new machine, based on new methods of balancing, has been developed.

2 The principle of the original machine is indicated in Fig. 1, which shows a lathe bed which takes the form of a beam hinged at one end and supported by a spring at the other. The body to be tested must first be brought into static balance, after which it is rotated in bearings supported by the beam. If the body is dynamically unbalanced its rotation will cause the beam to vibrate in a vertical plane with a period of oscillation equal to the period of rotation of the body.

3 Suspended from the beam is a second body in the form of a so-called squirrel cage consisting of two circular disks carrying an even number of rods so arranged as to slide in holes in the disks. The cage rotates in unison with the body to be tested and a state of unbalance in this body introduces a centrifugal couple which is neu-

[1] New Orleans Meeting, 1916; Trans.Am.Soc.M.E., vol. 38, p. 367.

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers.

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tralized by displacing the rods in the cage until an equal compensating couple has been introduced. The distances that the rods are displaced serve as a measurement of the amount of unbalance to be provided for and counterbalanced in the piece under test.

4 The improvements upon this machine, referred to above, were as follows:

a The substitution for the cage of a two-point element consisting of two disks, *A* and *B*, each with a pin projecting from its face, as shown in Fig. 2. The disk *A* is fixed to its shaft and the disk *B* is arranged to slide on the shaft through the use of a feather key *f*. It is clear that when the two disks are in contact they will balance each other;

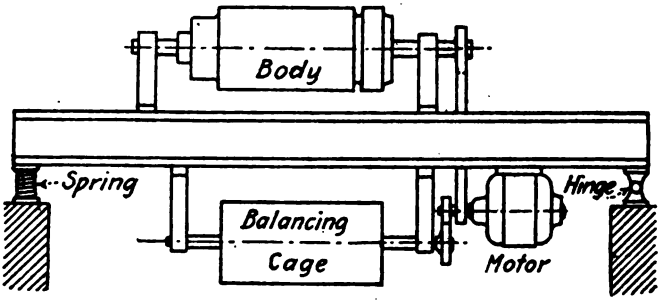

FIG. 1 SQUIRREL-CAGE TYPE OF DYNAMIC BALANCING MACHINE

but when separated they will introduce a certain centrifugal couple according to the weight of the pins and the distance between the disks, which latter can be varied while the apparatus is in motion

b A planetary arrangement by which the relative angular position of the body and the disks (or cage) can be varied while the machine is in operation

c The application of a principle whereby the disks (or cage) may be arranged to answer the problem of static balance as well as dynamic balance.

NEW METHODS

5 The new methods which have been developed and applied in a new type of machine for combination static and dynamic balancing will now be described.

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STATIC BALANCE

6 As a result of a great deal of study of the problem of static balance I have been forced to admit that too much has been taken for granted in relation to this subject. Static balance is not a trifling problem to be solved easily by placing a rotating body on parallel ways or rollers, as has commonly been supposed. While it is true that static balance can be found without much trouble in the case of bodies of light weight or where the operating speeds are comparatively slow, there are other cases which are much more difficult. For

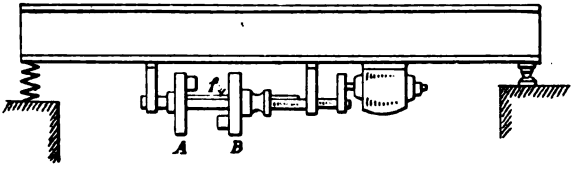

FIG. 2 TWO-POINT BALANCING ELEMENT

example, consider a gyroscope wheel whose weight is about 50 lb. or so, running at, say, 10,000 r.p.m.; or a turbo-rotor whose weight is 10,000 lb. and whose speed is 3600 r.p.m. Neither of these extreme cases can possibly be handled with any degree of success by placing the bodies on ways; and yet, unless static balance is perfect, no dynamic balancing machine can be expected to give reliable results.

STATIC BALANCE BY MEANS OF PARALLEL WAYS

7 It may be well to point out that in balancing by the aid of parallel ways there is a limit to the load which can be safely borne by the journals in contact with the ways. A safe load for each journal appears to be 750 lb. per inch of width per inch diameter of journal.[1] For instance, if the ways are 1½ in. wide and the journal diameter is 10 in., then each side will carry almost 12,000 lb. without any danger of forming permanent flat spots.

8 It would be of interest if one could estimate the sluggishness of action of a body on the ways under different conditions. The

[1] According to the writer's remembrance, this figure was first given him by the engineers of the Standard Roller Bearing Co. many years ago, and has since been revised by him in connection with other practical data which he was able to gather from different sources.

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older theories of rolling friction, as proposed by Coulomb, Morin and Dupuit, do not seem to lead to very reliable results. Résal's formula [1] is probably much more reliable and is here reproduced in simplified form (steel on steel):

$$f = 0.056\sqrt{1/(1 + 79/D)}$$

where f is the length of the flat contact of shaft with the way and D is the diameter of shaft, both in inches. It appears that the weight does not enter into the formula, and in general its results should not

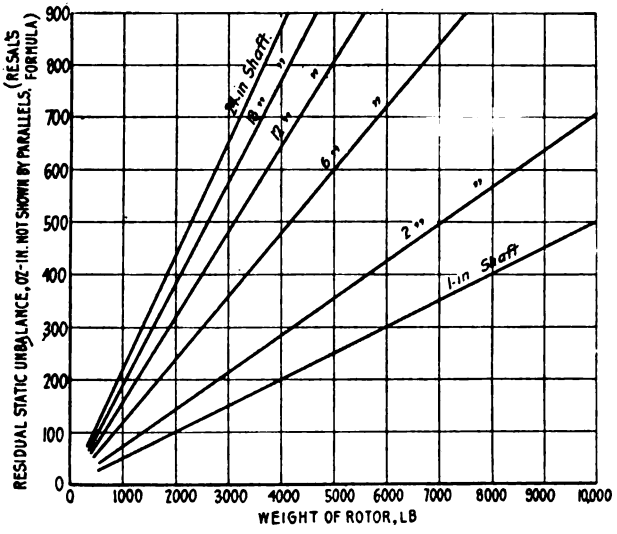

FIG. 3 DIAGRAM TO ILLUSTRATE PROBABLE RESIDUAL UNBALANCE OF BODIES BALANCED ON TESTING WAYS

be considered as extending to extremes, but only as characterizing the average run of things as they are met with in practice.

9 The diagram in Fig. 3 has been roughly plotted to illustrate the probable *sluggishness* or *residual unbalance* which *may* remain in a body that has been brought into apparent balance by testing on ways. The chart is based on Résal's formula, and, as it is intended simply to illustrate the meaning of the formula, values have been exaggerated by plotting shafts of small diameter against weights altogether inconsistent therewith. The chart is easily read: for instance, if a rotor weighs 4000 lb. and diameter of its shaft is 6 in.,

[1] Résal, Traité de Mécanique Générale, T. 11, p. 6.

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then the residual unbalance may be as great as 480 ounce-inches, or, say, 2½ lb. on a 12-in. radius. It is useless to put a body statically unbalanced to such an extent (or even to 50 per cent of this) on any dynamic balancing machine. Satisfactory results cannot possibly be derived from such tests. An actual case of residual unbalance, typical of many others, is of a shaft having a diameter of 2⅛ in., a weight of 88 lb. and a residual unbalance of 0.915 ounce-inches. The width of the balancing ways was $\frac{5}{16}$ in. (cast iron chilled and ground).

10 Considering the phenomenon of rolling friction from the standpoint of higher theories of elasticity (Hertz), the following tentative formula was derived for residual unbalance:

$$M = 0.0004648\, P \sqrt{PD}$$

where M is the residual moment in ounce-inches, P the weight per unit of contact length (that is, per inch of combined width of ways), and D the diameter of shaft in inches (steel on steel). The constant may be considered to be rather tentative, but with the advent of a machine capable of establishing perfect static balance it will not take long to find more reliable values for it.

11 According to this formula, if an armature weighed 12,000 lb. and had a shaft diameter of 8 in., the sluggishness or residual balance when placed on ways 1 in. wide, would be:

$$M = 0.0004648 \times 6000 \sqrt{6000 \times 8} = 614 \text{ oz-in.},$$

or over 3 lb. on a 12-in. radius. At 3600 r.p.m. the centrifugal force due to such residual unbalance would be more than 14,000 lb.

USE OF CENTRIFUGAL FORCE IN BALANCING

12 As previously stated, my earlier machine for dynamic balancing was based on the introduction of *centrifugal couples*, created by the operator to offset the effect of the disturbing centrifugal couple, constituting unbalance in the rotating body. Likewise, a machine for static balancing can be based on the same principle, but long study of the subject has led me to the conclusion that the whole problem of balance, static and dynamic, can be reduced to the principle of a single *centrifugal force* acting on a properly constrained body. Such centrifugal force can be created by the operator, within a rotating body, by such means as, for instance, the *clamps* of which two designs are here shown (Figs. 4 and 5). As will be explained, such clamps may be used to offset the effect of static or dynamic unbalance

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in a rotating body, as the case may be, and to record the extent of such unbalance. They are carefully made and so calibrated that the centrifugal force may be given as a function of some linear dimension, read directly or measured by an accurate scale. The first clamp is easier to make and check for accuracy, while the second design is much handier for quick adjustment on the shaft of a rotating body.

MEANS FOR SECURING STATIC BALANCE

13 In order to register the effect of static unbalance of a body, or the correction introduced by means of such a clamp as described, the body must be placed in such a condition that its oscillations are

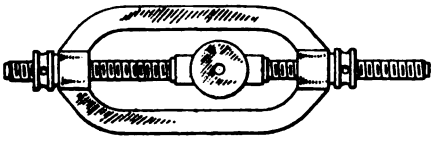

FIG. 4 CLAMP NOW USED IN SECURING STATIC AND DYNAMIC BALANCE

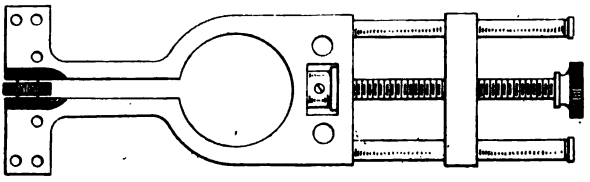

FIG. 5 A SECOND TYPE OF CLAMP

emphasized or magnified to an extent that will be visible to the eye; otherwise its unbalance, even if considerable, will not be noticeable and will only result in increased pressure on the bearings. Thus, in a badly unbalanced automobile engine it is most often possible to pick out a range of speeds where the engine will appear to work smoothly; and many an electric motor with badly unbalanced rotor will apparently run well, simply because its speed may be far away from that which would insure synchronism of the rotation with the oscillation of bearing supports.

14 Now, suppose we have a frame, suspended as shown in Fig. 6 and capable of a certain period of swinging oscillation. If the body, statically unbalanced, is operated at a speed corresponding to the

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period of oscillation, the oscillations of the frame will become violent and can be readily registered by any suitable dial-gage indicator. Here the body is imposing its own period on the frame, which thus performs what are known as forced vibrations of the same period. Our task is then to adjust the speed of the body so that the period of such forced oscillation will be equal to that of the natural oscillation of the frame and body (at rest).

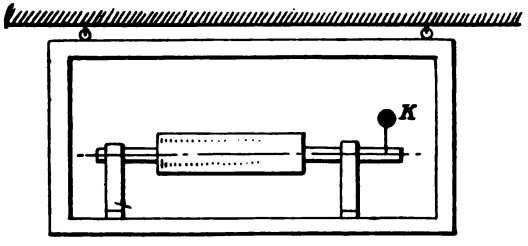

FIG. 6 BODY SUPPORTED IN SWINGING FRAME FOR SECURING STATIC BALANCE

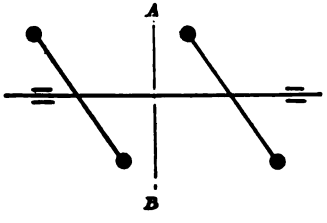

FIG. 7 UNBALANCED BODY WITH CENTER OF GRAVITY LYING IN ITS AXIS

15 In Lord Rayleigh's remarkable book [1] a most lucid explanation is given of this phenomenon of "step" or synchronism. Lord Kelvin's well-known device called a "vibrometer" is likewise based on this very principle. Of course, it is easy enough to see that a clamp K can always be so adjusted, both angularly and as regards its off-center position, as to nullify the oscillations of the frame, thereby solving the problem of static balance. No matter how heavy the body, it is always possible to place it into most minute balance by this method, where ordinary parallels would be altogether inoperative.

[1] Theory of Sound.

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DYNAMIC BALANCE

16 As regards dynamic balance, due, in a statically balanced body, only to the presence of a centrifugal couple, the following remarks can be made: In the first place the "theory" that this centrifugal couple is due to the fact that the centers of gravity of both halves of the body, cut through its center of gravity, do not lie on the axis of rotation, is radically wrong. Take, for instance, a skeleton body shown in Fig. 7. Its center of gravity is exactly on the axis of rotation, as also are the individual centers of gravity of each half, to the right and to the left from A–B. Yet such a body would be

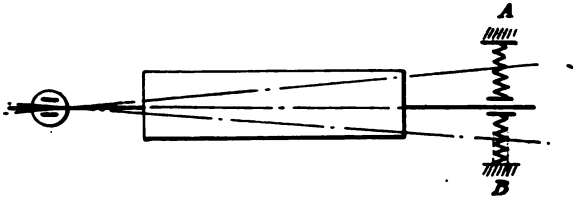

FIG. 8 ONE BEARING PIVOTED AND ONE FLOATING

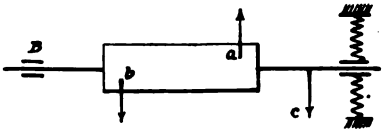

FIG. 9 CENTRIFUGAL COUPLE BALANCED BY A CENTRIFUGAL FORCE

manifestly out of balance (dynamically). Inversely, a body could readily be imagined to be both in static and dynamic balance, although each of its *halves* were statically out of balance. The only correct way to characterize dynamic balance is to say that the *products of inertia*, containing the axis of rotation, vanish;[1] or, to put it practically, that there is no centrifugal couple in any axial plane.

17 In the next place, if we constrain (pivot) one end of a rotating body (statically balanced but dynamically out of balance) while the other end is arranged to float in a bearing supported by springs so that it may move, say, in a horizontal plane, Fig. 8, then the oscillations of the body will be angular, as from A to B. Under these conditions the observer will be unable to tell whether the vibrations are

[1] Slocum, Theory and Practice of Mechanics, p. 297.

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due to a *force* (centrifugal) acting somewhere on the body or to a centrifugal couple, unless he knows beforehand that the body is in perfect static balance, under which condition the vibratory effect can be due only to dynamic unbalance. This being the case, in view of the reaction of the constrained end, it is perfectly possible to balance the effect of a centrifugal couple by means of a centrifugal *force*. Thus, in Fig. 9 if it is assumed that the dynamic unbalance is due to the couple *a–b*, it will always be possible to select a centrifugal force *c*, such that it will quiet the vibrating body, and because of its known distance from the bearing *B*, establish the exact value, sign and angular position of the disturbing centrifugal couple *a–b*.

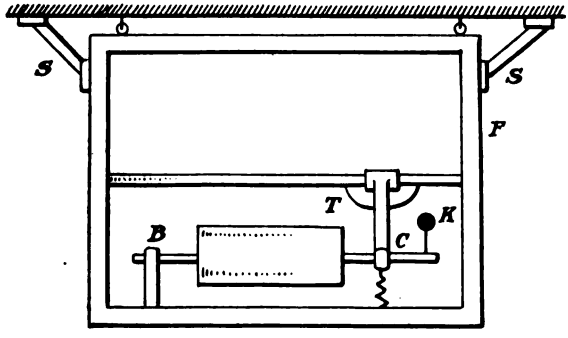

FIG. 10 BODY WITH ONE FLOATING BEARING, SUPPORTED IN RIGID FRAME FOR SECURING DYNAMIC BALANCE

18 It is thus clearly seen that it is possible to utilize a centrifugal force to good advantage in finding both static and dynamic unbalance of bodies; and combining the principles illustrated in Figs. 6 and 8, we have a combination static and dynamic balancing machine, of which the scheme is as follows:

DESCRIPTION OF COMBINATION BALANCING MACHINE

19 A frame *F*, Fig. 10, supports the bearings *B* and *C*, which carry the body. The frame has a swinging period of its own. The bearing *C* may either be locked, so that it acts exactly like the rigid bearing *B*, or else it may be allowed to float in a vertical plane, bringing into play certain resistances (springs) opposing its deflection from the neutral (vertical) position. The correcting centrifugal force is indicated by *K*.

20 Such a system is known in dynamics as a *system with two degrees of freedom*, in general being capable of two kinds of motion:

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swinging of the frame, the bearing C being maintained rigid; and swinging of the bearing C, the frame F being maintained rigid by such means as brackets S; while the most general motion consists of a combination of these two motions.

21 The operation of such a combination machine is very clear. In order to secure static balance we lock the bearing C and unlock the frame supports S. Then, by properly adjusting the magnitude and

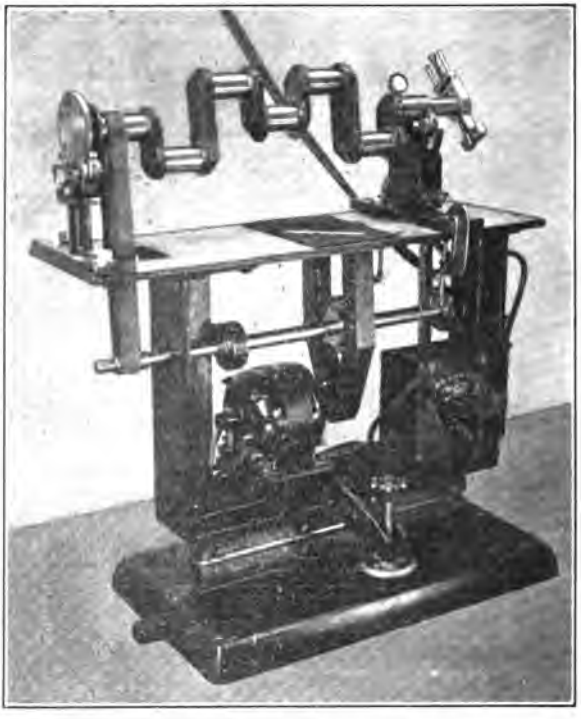

FIG. 11 COMBINED STATIC AND DYNAMIC BALANCING MACHINE

direction of K we can reduce to zero the bodily oscillations of the frame F, thus establishing the exact value and sign of static unbalance in ounce-inch units. As soon as this has been corrected, we lock the frame F and unlock the bearings C, when the same centrifugal force K, created by a suitable adjustment of the clamp as explained above, can be made to correct the body for dynamic unbalance, as illustrated in Fig. 9. The advantage of basing the results on centrifugal force instead of on a centrifugal couple is manifest, the former being a *fun-*

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damental, and the latter a *derived*, unit, so that the former is capable of much greater accuracy in adjustment and of more direct application than the latter.

22 Fig. 11 illustrates a balancing machine built in accordance with the scheme of Fig. 10. The yielding support, clearly shown on the right, has means for easy adjustment of its period, as likewise has the frame itself. The motor is of ⅓ hp. capacity and operates the body, through a countershaft, by a rubber belt. The balancing clamp is seen on the extreme right of the crankshaft. The oscillations are read by means of ordinary Starrett dial gages, graduated in thousandths of an inch. The precision which can be secured on such a machine is almost uncanny; it enables one to see the sluggishness of the method of balancing on ways and therefore the absolute lack of precision of dynamic balance that might be based on such results. A well-designed clamp is very easily handled and its correct position can be established in a few minutes. Its indications are capable of tabular interpretation, so that the operator has merely to carry out the simple instructions, worked out beforehand. Of course, it is clear that such a machine can be built for any size of body, or for any speed that may be desired

DISCUSSION

C. P. Crissey asked the author if any rotors had been balanced on his machine and then run at or through critical speed, and if so whether experience had indicated that it would be commercial to design multi-stage apparatus having packings between stages, with a critical speed below but in close proximity to the operating speed. In other words, could apparatus be balanced so closely that the critical speed could be disregarded?

H. G. Reist asked whether there was any method of marking the shaft or indicating where the counterweight was to go. With reference to the matter of getting a balance that would run at critical speed, he said that this was practically done in a different type of balancing machine in which the rotating body was supported by a flexible cable, but the effect was practically similar.

W. J. Baldwin described a method which he had devised and successfully used for balancing fans and other machines having

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parts attached to a central hub. The rotating part of the machine is first nearly balanced on knife edges and then two light radial arms are placed on its shaft, directly opposite to each other in order not to disturb the balance. Running balance is obtained by changing the position of one or both of these arms. If when both opposite the "heavy" side of the machine they do not hold the machine in running balance, they are made heavier. If found too heavy they are shortened. Minor adjustments are made by moving slightly one of the arms.

F. VAN BUREN CONNELL said that recent developments in the automobile and airplane industries had emphasized greatly the subject of balance, which already was known to be very important and was now considered a distinct branch of mechanical engineering and not a shop method at all. Up to the present time the methods of obtaining balance had been very crude. One of the old standbys had been the parallel ways referred to, which were only good for static balance, and then only under conditions of light weight and small journal bearing. With large journal sizes and heavy weights the results showed such a discrepancy that they positively prohibited the use of parallel ways for obtaining even static balance. With Mr. Akimoff's machine results were obtained with a mathematical exactness that had never been obtained before, and there was no guesswork about it — it was not a hit-or-miss system. By systematic trial adjustments they obtained the exact amount of unbalance and the exact plane in which they should drill or add weights to give that balance.

The subject of balancing was an extremely important one and a very practical one, too, because the actual work of indicating could be done by a mechanic. There should be an efficient balancing engineer, however, a new species, to direct the mechanic's work, because the subject required something more than the trial methods and the horse sense that had been applied to it so far.

THE AUTHOR, replying to Mr. Crissey, said that he thought the matter in question was a problem different from dynamic balance. It seemed to him that dynamic balance proper ended when a body was balanced in such a way that in a perfect vacuum, without any outside effort, it would run perfectly and without any oscillation whatsoever. Machines could be built commercially without very much trouble, because it as just was easy to get a near balance as to

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get perfect balance by the means described, and, of course, vibrations would not be set up except by the action of some outside agency. Torsional vibrations were an entirely different proposition and were due to the distribution of mass on the line of the shaft. The torsional problem, which was very difficult to solve, was illustrated by a plain shaft with a flywheel on either end.

Regarding Mr. Reist's question, he said that the amount and location of the counterweight were fully indicated by the position of the clamp, which could be quickly adjusted after a few trials. There was a way of making the clamp so that the adjustments could be made without stopping the machine, but that would be the subject of a communication by him at some future time.

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No. 1615

PLOTTING BLOWER-TEST CURVES

By A. H. Anderson, Chicago, Ill.
Member of the Society

To the several methods of plotting blower-test curves another method is here added, whose utility is demonstrated by the solution of problems from graphically recorded test data. Diagrams are given for impellers with blades tilted forward, with blades radial, and with blades tilted backward, the coördinates used being revolutions per minute and static pressure in inches of water. Two series of curves are given, one showing various rates of discharge in cubic feet per second, and the other the volumes discharged per second per horsepower.

SEVERAL ingenious methods of graphically representing centrifugal-fan characteristics are in use, and to these the writer adds another, which to the best of his knowledge is new.

2 To obtain the experimental data the fan is tested at several speeds, the discharge being varied by the use of different-sized orifices. Figs. 1, 2 and 3 show the curves for three fans which differ only in the angle of inclination of the blades, the coördinates being static pressure and speed. The curves connect points of equal capacity and also equal cubic feet per second per horsepower.

3 The use of the charts is best illustrated by the six problems which follow.

Problem 1 Required the input horsepower in Fig. 1 for 1360 r.p.m. and 2.7 in. static pressure.

Solution: The chart shows the fan is delivering 14.5 cu. ft. per sec. per horsepower with a capacity of 45 cu. ft. per sec. The input horsepower therefore is 45/14.5 = 3.1.

Problem 2 Required the mechanical efficiency in Fig. 1 at 1360 r.p.m. and various static pressures.

Solution:

a Cubic feet per second: read direct.

b Velocity pressure: find in Table 1.

c Dynamic or total pressure: add static and velocity pressure.

d Output horsepower: take product of cubic feet per second, dynamic pressure, and a constant depending upon temperature and pressure (for usual conditions constant = 0.0093).

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers.

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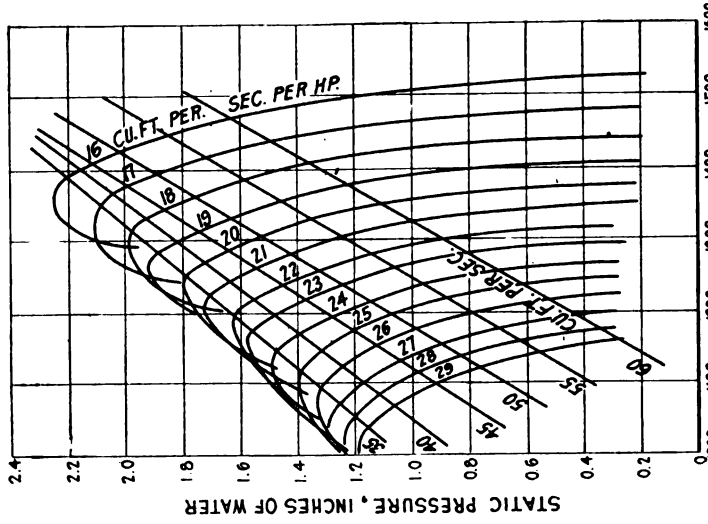

FIG. 2 CHARACTERISTIC CURVES, BLADES RADIAL

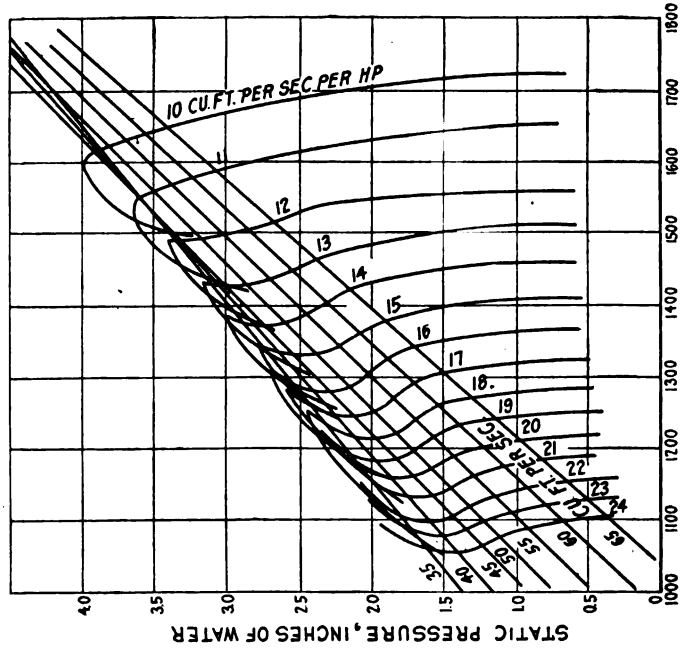

FIG. 1 CHARACTERISTIC CURVES, BLADES TILTED FORWARD

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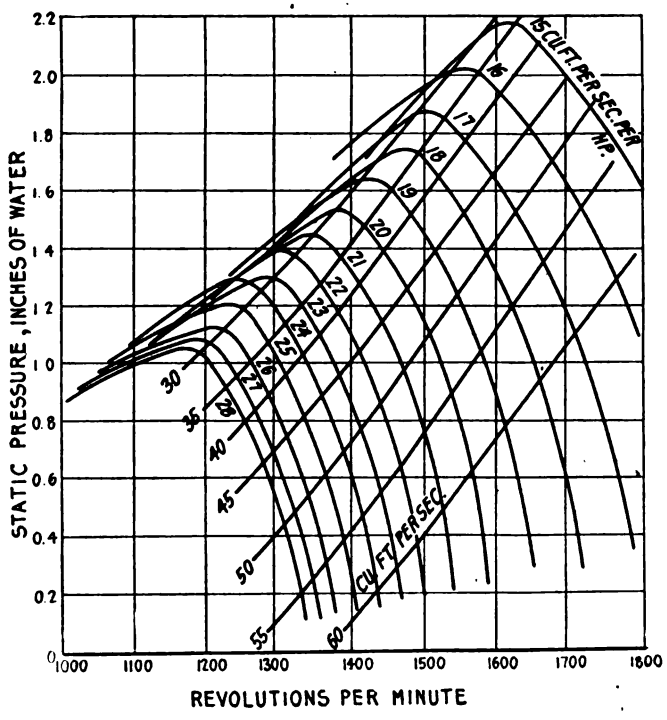

FIG. 3 CHARACTERISTIC CURVES, BLADES TILTED BACKWARD

TABLE 1 VELOCITY PRESSURES IN INCHES OF WATER FOR VARIOUS RATES OF DISCHARGE

Cu. ft. per sec.	Velocity pressure, in.	Cu. ft. per sec.	Velocity pressure, in.	Cu. ft. per sec.	Velocity pressure, in.	Cu. ft. per sec.	Velocity pressure, in.
36	0.250	44	0.375	52	0.520	60	0.700
37	0.264	45	0.390	53	0.540	61	0.720
38	0.280	46	0.410	54	0.562	62	0.740
39	0.294	47	0.425	55	0.585	63	0.760
40	0.310	48	0.445	56	0.605	64	0.790
41	0.325	49	0.463	57	0.628	65	0.810
42	0.340	50	0.483	58	0.650	.....	.....
43	0.357	51	0.500	59	0.670	.....	.....

e Input horsepower: divide cubic feet per second by cubic feet per second per horsepower.

f Mechanical efficiency: divide output horsepower by input horsepower.

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These successive steps are tabulated below. Note that the zone of maximum efficiency is found at the concave part of the series of curves.

Static pressure, in. water	*a* Cu. ft. per sec.	*b* Velocity pressure, in. water	*c* Total pressure, in. water	*d* Output hp.	*e* Input hp.	*f* Mech. effy., per cent
2.8	35.0	0.23	3.03	0.95	2.33	40.5
2.4	52.5	0.53	2.93	1.56	3.62	43.0
2.0	62.0	0.74	2.74	1.73	4.07	42.5
1.8	65.0	0.81	2.61	1.72	4.43	41.8

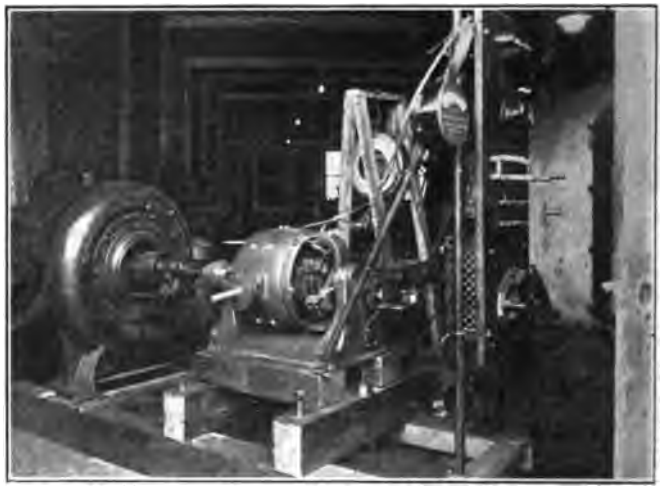

FIG. 4 APPARATUS FOR OBTAINING POWER INPUT

PROBLEM 3 Required the mechanical efficiency in Fig. 2 at 1300 r.p.m. and various static pressures.

Solution: See method used in Problem 2 and the following tabulation. Note that the zone of maximum efficiency is found along the 40-cu.-ft.-per-sec. line.

Static pressure, in. water	*a* Cu. ft. per sec.	*b* Velocity pressure, in. water	*c* Total pressure, in. water	*d* Output hp.	*e* Input hp.	*f* Mech. effy., per cent
2.0	30	0.17	2.17	0.67	1.67	40.0
1.8	42	0.34	2.14	0.92	2.21	41.5
1.4	52	0.52	1.92	1.02	2.56	40.0
1.0	58	0.65	1.65	0.98	2.70	36.0

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PROBLEM 4 Required the mechanical efficiency in Fig. 3 at 1400 r.p.m. and various static pressures.

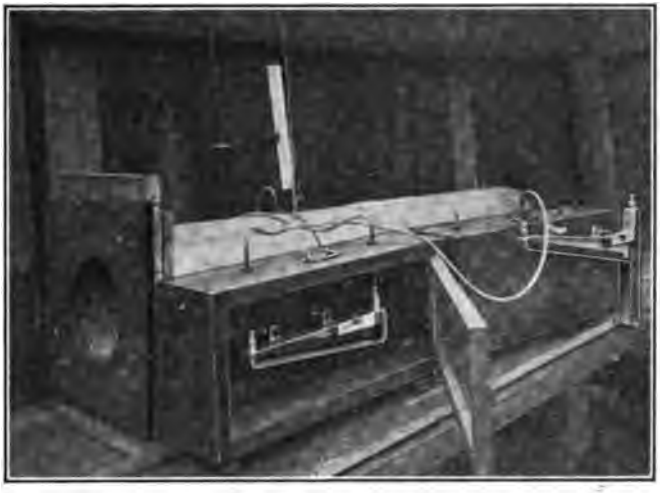

FIG. 5 APPARATUS FOR OBTAINING OUTPUT

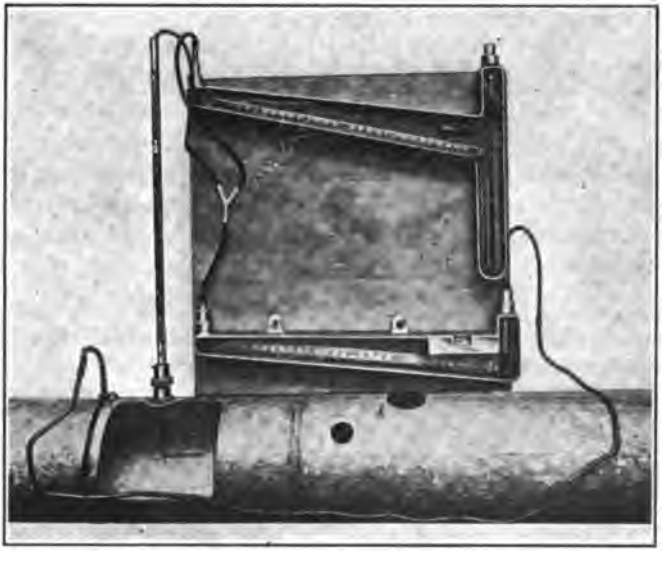

FIG. 6 CONNECTIONS TO DIFFERENTIAL GAGES

Solution: See method used in Problem 2 and the following tabulation.

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Static pressure, in. water	*a* Cu. ft. per sec.	*b* Velocity pressure, in. water	*c* Total pressure, in. water	*d* Output hp.	*e* Input hp.	*f* Mech. effy., per cent
1.6	30	0.17	1.77	0.54	1.58	34.0
1.2	40	0.31	1.51	0.61	1.82	33.5
0.8	48	0.44	1.24	0.61	2.08	29.3

PROBLEM 5 Required the r.p.m. and static pressure to change from 1320 r.p.m. and 50 cu. ft. per sec. to 55 cu. ft. per sec. (Fig. 1).

Solution: Follow the 1320-r.p.m. line down to 50 cu. ft. per sec., where the static pressure is found to be 2.29 in. The new static pressure will then be

$$2.29 \times \frac{(55)^2}{(50)^2} = 2.77 \text{ in.}$$

The r.p.m. corresponding to a static pressure of 2.77 in. and 55 cu. ft. per sec. is 1450.

PROBLEM 6. The speed of a fan (Fig. 2) is changed from 1160 r.p.m. to 1500 r.p.m. The original static pressure is 1 in. Increase the capacity in the ratio of the speeds, 1500/1160 = 1.3, and determine ratio of new input horsepower to original, and ratio of new static pressure to original.

Solution: The capacity at 1 in. and 1160 r.p.m. is 48 cu. ft. per sec., therefore the new capacity will be 48 × 1.3 = 62 cu. ft. per sec. At 1500 r.p.m. and 62 cu. ft. per sec. the static pressure is 1.6 in. and the ratio is

$$\frac{1.6}{1} = 1.6$$

or approximately the square of 1.3.

The horsepower at 1 in. static pressure and 1160 r.p.m. is

$$\frac{48}{26.5} = 1.8$$

and the horsepower at 1.6 in. and 1500 r.p.m. is

$$\frac{62}{15} = 4$$

the ratio being

$$\frac{4}{1.8} = 2.2$$

which is the cube of 1.3. Hence, when the capacity of a fan varies directly with the r.p.m., the static pressure varies directly with the square of the r.p.m. and the horsepower directly with the cube of the r.p.m.

4 The general arrangement of the apparatus for obtaining the power input is shown in Fig. 4. The fan was directly driven by a Sprague electric dynamometer, and the torque was measured by a Kron springless scale. The output apparatus is shown in Fig. 5. Dynamic pressures were obtained by a pitot tube, and static pressures by a piezometer ring with four openings through the wall of the pipe. Fig. 6 shows the connections from the pitot tube and piezometer to the differential gages. This view shows also the method of securing the orifice plate to the discharge pipes.

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DISCUSSION

J. M. SPITZGLASS (written). The curves given in the paper disclose many interesting features in the characteristic properties of the various types of blowers, which could not be very well shown in the usual pressure-volume curve of the blower. It is interesting to note that in Fig. 1, representing the characteristic curve for blades tilted forward, the volume lines are uniformly converging toward the higher speed, so that some of them cross each other, even within the limited region of the curve. This would indicate that at the higher speed of this special blower there is practically no variation in the pressure for any volume delivered by the blower, or rather the least variation in the pressure would change the volume from a maximum to a minimum, and vice versa, and it would be very inefficient to use a blower of that kind where a more or less constant volume of air is required.

In Fig. 2, the characteristic curve for blades radial, the volume lines are less converging than in Fig. 1; while in Fig. 3, the characteristic curve for blades tilted backward, the volume lines are practically parallel to each other, which means that in this kind of blower the volume of air delivered can be kept more or less uniform, even though the resistance to the flow should vary to a certain degree.

In this experimental case the discharge of the fan was varied by the use of different-sized orifices at the outlet of the fan. In the practical operation of blowers it is not so easy to control the resistance offered to the flow of the air. The air may be blown through a thick fuel bed, which may vary in height and also in resistance, and in such cases it is not the static pressure, nor even the mechanical efficiency, that interests operators as much as the number of cubic feet per horsepower that can be obtained from the blower, and curves plotted in this manner showing the amount of air that can be obtained for any condition are very valuable for that purpose, because they show at a glance under what conditions it is possible to obtain the maximum quantity for a given amount of power used on the blower.

Regarding the mechanical efficiency shown for the given blowers, I would like to ask the author why it is so low, not being much over 40 per cent in any one of them, and why the blower with the blades tilted backward shows the lowest efficiency of all, when theoretically this kind of blade should show a higher efficiency than the others.

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F. R. STILL wrote that while the author's curves were interesting, and perhaps might be valuable for some purposes, he thought the most useful curves for all purposes of fan or blower application were those of the kind employed in the charts of the American Blower Company, which were developed from characteristic curves plotted from test results. In his opinion, no other method covered the performance of a fan so completely, and at the same time cleared up what

TABLE 2 COMMON BASIS: PRESSURE AND R.P.M.

Basis		Performance						
			Total Output, Cu. Ft. per Sec.			Efficiency, Cu. Ft. per Sec. per Hp.		
Pressure, Inches of Water	Rev. per Min.	Values	Blades Tilted Forward	Blades Radial	Blades Tilted Backward	Blades Tilted Forward	Blades Radial	Blade Tilted Backward
1.50	1400	Actual	73.0	57.0	32.5	15.00	17.95	20.05
		Relative	100.0	78.0	44.5	74.80	89.50	100.00
1.25	1400	Actual	76.3	60.9	39.5	15.10	18.40	21.40
		Relative	100.0	79.8	51.8	70.60	86.00	100.00
1.00	1400	Actual	80.0	64.1	45.0	15.20	18.90	22.45
		Relative	100.0	80.1	56.3	67.80	84.30	100.00
1.25	1300	Actual	68.0	54.6	31.2	17.35	21.05	23.50
		Relative	100.0	80.3	45.8	73.80	89.70	100.00
1.00	1300	Actual	72.0	58.2	37.4	17.50	21.70	25.20
		Relative	100.0	80.9	51.9	69.50	86.20	100.00
0.75	1300	Actual	75.0	61.8	43.1	17.62	22.30	26.57
		Relative	100.0	82.5	57.5	66.40	84.00	100.00

otherwise was so frequently very puzzling in results from fan installations, especially to those who did not have to deal with fans frequently enough to understand them thoroughly.

G. F. GEBHARDT (written). I have applied the author's curves to comparative tests of a number of fans of various makes, and find that the commercial characteristics most desired are brought out in a much more satisfactory manner than with the customary method of plotting results. It is true that considerable time is required to

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plot the curves as indicated, but the ease with which the various problems involved may be calculated from the graph may greatly justify the initial expenditure of time. The author makes no claims as to the accuracy with which the investigation was conducted, but I had the privilege of studying his test methods and was greatly im-

TABLE 3 COMMON BASIS: TOTAL OUTPUT AND CU. FT. PER HP. PER SEC.

Basis			Performance					
			Pressure, Inches of Water			Rev. per Min.		
Total Output, Cu. Ft. per Sec.	Efficiency, Cu. Ft. per Sec. per Hp.	Values	Blades Tilted Forward	Blades Radial	Blades Tilted Backward	Blades Tilted Forward	Blades Radial	Blades Tilted Backward
40	16	Actual	2.40	2.16	1.93	1278	1405.0	1612.0
		Relative	124.30	112.00	100.00	100	110.0	126.1
40	19	Actual	2.14	1.83	1.52	1182	1295.0	1477.0
		Relative	140.70	120.30	100.00	100	109.5	124.9
40	22	Actual	1.77	1.55	1.17	1100	1220.0	1382.0
		Relative	151.20	132.40	100.00	100	110.0	125.8
50	16	Actual	2.12	2.02	1.70	1282	1433.0	1680.0
		Relative	124.70	118.70	100.00	100	111.8	131.0
50	19	Actual	1.80	1.63	1.25	1196	1329.0	1546.0
		Relative	144.00	130.20	100.00	100	111.0	129.4
50	22	Actual	1.32	1.32	0.87	1122	1258.0	1440.0
		Relative	151.70	151.70	100.00	100	112.0	128.2
60	16	Actual	1.87	1.63	1.29	1333	1470.0	1770.0
		Relative	145.00	126.30	100.00	100	110.3	132.8
60	19	Actual	1.40	1.23	0.78	1238	1378.0	1615.0
		Relative	179.30	157.60	100.00	100	111.2	130.4
60	22	Actual	0.92	0.89	0.37	1143	1300.0	1490.0
		Relative	248.70	240.50	100.00	100	113.6	130.2

pressed with the painstaking and exacting care with which all measurements were made and recorded. The paper, though brief, is a marked acquisition to the art of blower testing. I would like to ask the author why the capacity curves between 0 and 35 cu. ft. per sec., Fig. 1, have been omitted.

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C. M. SPALDING (written). The curves given in the paper bring out very clearly certain phases of blower action, and it would be very desirable if the author would add some definite information about the dimensions of the fans, and also tell whether the blades were plain or curved, etc.

In examining the data presented, the writer has been interested to see what other aspects of the matter would appear by taking the information furnished by the author and comparing it in other

TABLE 4 COMMON BASIS: TOTAL OUTPUT AND PRESSURE

Basis		Performance						
			Efficiency, Cu. Ft. per Sec. per Hp.			Rev. per Min.		
Total Output, Cu. Ft. per Sec.	Pressure Inches Water	Values	Blades Tilted Forward	Blades Radial	Blades Tilted Backward	Blades Tilted Forward	Blades Radial	Blades Tilted Backward
45	2.000	Actual	17.75	16.90	14.95	1219.0	1378.0	1703.0
		Relative	100.00	95.10	84.20	100.0	113.0	139.8
45	1.625	Actual	20.70	20.27	17.25	1145.0	1281.0	1583.0
		Relative	100.00	97.90	83.30	100.0	111.9	138.3
45	1.250	Actual	23.50	24.33	20.25	1071.0	1184.0	1463.0
		Relative	100.00	103.60	86.30	100.0	110.5	136.6
55	1.750	Actual	17.45	16.67	14.90	1250.0	1430.0	1775.0
		Relative	100.00	95.50	85.40	100.0	114.4	142.1
55	1.375	Actual	20.38	19.80	16.80	1175.0	1338.0	1670.0
		Relative	100.00	97.20	82.50	100.0	113.8	142.1
55	1.000	Actual	24.42	23.60	19.30	1100.0	1246.0	1565.0
		Relative	100.00	96.50	79.00	100.0	113.2	142.2

relations, more especially as regarding the relative performance of the three types of fans. He has accordingly constructed Tables 2, 3 and 4 by taking two values as a common basis for all three types of fans and setting against them the variable values of the other items covered in these data. The variable items are stated both in the actual values taken from the curves and in the proportionate values by assuming some one of the three types of the fans as unity, or rather 100 per cent, and comparing the performance of the other two types of fans. It will be noted that these tables do not select the

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most favorable condition of operation of all three types of fans, as in order to make the comparison it is necessary to select as a common basis points which appear on all three of Professor Anderson's curves, but even with this limitation they are very interesting.

THE AUTHOR. Professor Gebhardt brings up the point of why the curves between 0 and 35 cu. ft. per sec. have been omitted in Fig. 1. This was due to the fact that for less than 30 cu. ft. per sec. the curves overlapped and would have been indistinguishable in the small scale to which the figures were drawn for the cuts. Curves drawn to a larger scale than shown in the figures illustrate the performance of the blowers very clearly.

Mr. Spitzglass' application of the curves to forced-draft practice is important. Another application is that to ventilation systems where it is necessary to move air against the friction in the ducts. The correct speed for a certain friction head and volume may be readily selected, or if the friction head is diminished by shutting some of the air outlets the proper blower speed may be determined from the chart and the blower slowed down, resulting in economy of power.

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No. 1616

CROSS-CURRENT PREDETERMINATIONS FROM CRANK-EFFORT DIAGRAMS

By Louis Illmer, Milford, Conn.
Member of the Society

This paper is a research study into the cause of excessive cross-current flow between paralleled alternators when driven by reciprocating engines. Cross-currents determined by ammeter measurement show a flow far greater than can be traced directly to the unevenness of the primary crank-effort forces.

The uneven crank effort of the reciprocating engines does, however, superimpose small oscillatory displacement movements upon the rotating paralleled armatures, which in turn cause a correspondingly small cross-current flow, the pull of which is still sufficient to set up independent armature oscillations. The time period imposed by the cross-current pull differs from that imposed by the primary crank-effort forces, and the reactive effect is a periodic variation in the engine load against which the uneven crank effort must work.

This condition is shown to be conducive to cumulative armature-displacement movements, since at times these two distinct periodic forces, i.e., excess effort and cross-current pull, act in unison, while subsequently they act in opposition. The combined action of these two forces subjects the rotating wheel parts to a cumulative oscillatory movement, the amplitude of which may readily build sufficiently to account for the relatively heavy cross-current flow found by actual measurement.

The theory underlying cumulative motions of this kind is developed, and formulæ are derived for predetermining the maximum armature-displacement shift and accompanying cross-current flow that may be expected for any given set of conditions.

The character of motion and the maximum amplitude of such cumulative oscillations are found to depend largely upon the relation which the time period of the excess crank effort bears to that of the cross-current pull. The crank-effort period is fixed by the cylinder arrangement and engine speed, while the cross-current-pull period is found to be most readily controlled by the selection of a suitable wheel weight.

The wheel-weight constants prescribed for paralleled reciprocating-engine units provide a guide for confining the cumulative armature oscillations within satisfactory limits. When a relatively light wheel is used for such engines, the resulting oscillatory movement is likely to have a comparatively rapid period and its maximum cumulative amplitude may be expected to be approximately twice that which occurs when using a heavy wheel oscillating with a relatively slow period.

The author advocates a reasonably heavy wheel as most likely to obviate excessive cross-current flow, mainly because of its beneficial secondary effects. The greater maximum amplitude of oscillation in the case of the relatively light wheel may lead

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to serious electrical disturbances, and under adverse conditions the detrimental secondary effects of the more rapid cumulative oscillations may become so aggravated as completely to upset the regulating functions of the engine governor.

The characteristic behavior of paralleled alternators is briefly set forth in the Appendix by means of vector diagrams. Therein is also discussed the manner in which periodic displacement movements of the paralleled armatures affect a momentary change in engine load.

The paper further treats of the principles underlying harmonic motion as applied to the effect which uneven crank-effort forces exert upon the rotating wheel mass. Wheel-displacement increments, graphically determined, are compared with those approximated by the more direct method of calculation.

In discussing the subject of harmonic armature oscillations and their application to paralleled alternators, the author points out reasons for considering untenable some of the basic assumptions made in the German literature relating to this subject. Cross-current determinations made by the author upon a set of paralleled 500-hp. gas engines are analyzed with the view of substantiating the contention as to the defect in the Rosenberg theory, and Bonte's deductions based thereon.

WHENEVER alternating-current generators are driven by reciprocating engines, the fluctuating crank effort causes oscillatory movements to be superimposed upon the rotating armature parts. In parallel operation such displacement movements are subject to a peculiar cumulative action, which, under adverse conditions, is liable to become so violent as to drive the armature far out of its course of uniform rotative speed. The present paper deals with the cause and effect of such cumulative action.

2 Acting alone, the irregular primary crank effort of the reciprocating engines accounts for but a relatively small portion of the excessive displacement movement to which the armature is subjected in parallel operation. Such small armature oscillations do, however, give rise to cross-current forces, which in turn tend to set up independent armature-displacement movements. The combined action of these two distinct periodic forces is likely to superimpose cumulative armature-displacement movements upon the rotating armature of far greater amplitude than could be produced by either component force acting alone.

3 The method deduced in this paper for arriving at such resultant armature-displacement increments is based upon finding the equivalent effect of the crank-effort and the cross-current-pull forces in terms of their respective sinuous sequence of force application. It will be shown that the actual crank-effort curve of any normal reciprocating engine may be approximated quite closely by means of an equivalent sine curve and that its characteristic accelerating effects may be expressed in terms of fairly simple harmonic-motion formulæ.

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Furthermore, the independent sinuous oscillations which the periodic cross-current pull tends to superimpose upon paralleled armatures, may likewise be taken into account by formulæ of this kind.

4 It will further be shown that when a sinuous crank effort of a reciprocating engine works against a variable resistance, as fixed by the surging cross-current pull of the generator, the conditions become favorable for imposing cumulative oscillations upon the rotating armature and wheel parts. These parts are then alternately accelerated and retarded by the combined action of two distinct periodic forces, each of which has an independent period and tends to set up independent armature oscillations. At times these two forces will be acting together, while at other times they will be acting in opposition, thus subjecting the armature and wheel parts to a cumulative oscillation about an imaginary position corresponding to that of uniform rotation. The period of this resultant oscillation is usually larger than either of the component movements, while its amplitude may be expected to build up until it reaches a maximum.

5 The derived formulæ make possible the predetermination of the probable ultimate armature-displacement shift as measured from an imaginary reference position, for any given set of assumptions as to characteristics of generator construction, crank effort, and wheel weight. The character and maximum amplitude of the cumulative armature movements are found to depend largely upon the relation between the time period of the sinuous crank-effort curve and that of the cross-current-pull curve. Under normal conditions the difference in period between these two curves is most readily controlled by the selection of a suitable wheel weight.

6 When a light wheel is used for paralleled reciprocating engines, the armatures oscillate in a relatively rapid period and the maximum cumulative armature-displacement shift is shown to be approximately twice as large as when a relatively long resultant period of oscillation is obtained by the use of a heavy wheel.

7 The secondary effects which accompany the use of a light wheel are more likely to upset the engine regulation and in other ways lead to detrimental electrical disturbances. In the event that the wheel weight and governor characteristics are not aptly chosen, the resulting cumulative armature oscillations may set up a heavy cross-current flow of such magnitude as to interfere seriously with the successful operation of the paralleled generators.

8 Troubles of this nature have repeatedly led to controversy as to whether the engine or the generator builder should be held

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responsible for the difficulties encountered. The present research study was undertaken with a view of finding the cause of such failures and of establishing a satisfactory basis for obviating abnormal cross-current flow.

9 The subject will be treated in the following order, viz.:

a Principles underlying harmonic motion and their application in estimating initial armature displacements that result from the uneven primary crank effort of a reciprocating-engine drive

b The effect of such periodic displacement movements upon a single a.c. generator when connected to independent bus bars

c The effect of periodic armature oscillations upon paralleled generators in setting up a variable resistance against which the engine must work; discussion of the cumulative oscillations which are likely to occur whenever a variable load of this kind is driven by the fluctuating crank effort of a reciprocating engine

d Conclusions

e Appendix: Characteristic behavior of an alternating-current generator, and other electrical aspects of the parallel-running problem relating especially to cross-current pull and its effects in causing periodic variations in the engine load.

INTRODUCTORY

10 When a reciprocating engine works against a *constant* load, the increment of flywheel displacement resulting from its uneven crank effort is dependent upon the inertia of the wheel. Its mass is alternately accelerated and retarded in proportion to the undulating character of the crank-effort forces, and for present purposes the resulting change in the wheel velocity may be taken as a convenient measure of such crank-effort irregularity.

11 The average wheel velocity may be assumed to coincide with that of an imaginary wheel rotating at absolutely uniform speed, such that any velocity change induced by the variable crank effort will cause the actual wheel to lag or lead with respect to the virtual position fixed by the reference standard.

12 Expressed mathematically, the foot-pounds of energy absorbed in raising the flywheel velocity from V_2 to V_1 =

$$\frac{1}{2} m (V_1^2 - V_2^2) = m \left(\frac{V_1 + V_2}{2} \right) (V_1 - V_2) = 2 m V_0 v_0 = \Delta W_0 \ldots [1]$$

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where $V_0 = (V_1 + V_2)/2$ = reference standard for uniform rotation, *i.e.*, synchronous speed as measured by the average crankpin velocity in ft. per sec.

$v_0 = (V_1 - V_2)/2$ = maximum crankpin velocity change as measured with respect to the reference standard V_0

$2\,v_0/V_0 = \delta_0$ = coefficient of speed fluctuation as determined from the primary crank-effort diagram

$m = \frac{G}{g}\left(\frac{\rho}{R}\right)^2$ = equivalent units of wheel mass transferred to the *crankpin* radius R

$\Sigma \frac{G}{g}\rho^2$ = equivalent moment of inertia of the crankshaft weights, g being gravity acceleration at 32.2 ft. per sec. per sec.

G = equivalent rim weight of wheel, lb., which is equal to the weight of the rim plus about 1/10 rim weight for arm allowance, plus the armature weight as transferred to the center of gravity of the wheel rim ρ.

13 It will be seen from the above equation that the fluctuating energy ΔW_0 taken up or given out by the wheel is directly proportional to the factor v_0, and that the extent to which any uneven crank effort is capable of inducing such a velocity increment is dependent upon the mass and initial velocity of the wheel.

14 Assuming a reciprocating engine to work with a sinuous crank effort, the phase relation between the velocity change and displacement increment which it imparts to the wheel is shown in Fig. 1. The common abscissa is taken on a time basis which is proportional to the crankpin travel.

15 The upper sine curve represents the variable crank-effort force drawn about the base line XX, which ordinate represents the mean turning force P_c acting normal to the crankpin radius. The sectioned area $\pm\Delta W_0$ denotes the fluctuating energy that must be successively taken up and given out by the flywheel parts in order to equalize the sinuous crank effort.

16 The resulting velocity change as measured at the crankpin is indicated by the sinuous line superimposed upon the mean or

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synchronous velocity base YY. The sequence of the displacement increments is indicated by the lower sine curve plotted with respect to the base line ZZ, which represents the reference position assumed by the crankpin when rotating at the uniform synchronous speed V_0.

17 Restricting the interplay of the fluctuating energy ΔW_0 to that exchanged during any one-stroke period of the engine, the coefficient of energy fluctuation becomes equal to

$$K = \frac{\Delta W_0}{W_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [2]$$

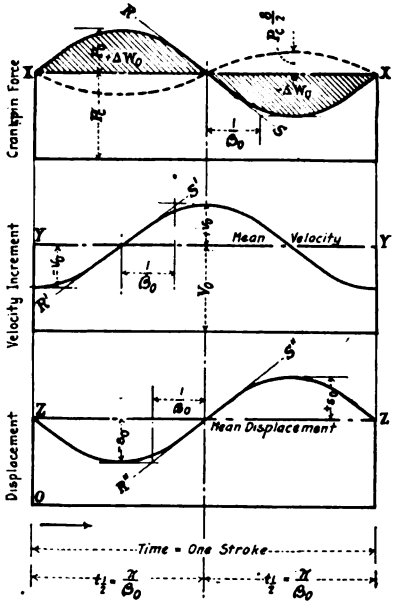

FIG. 1 SINUOUS CRANK-EFFORT DIAGRAMS

where K = coefficient of energy fluctuation, which is also equal to one-half the mean ordinate of the lobe area ΔW_0 divided by mean turning effort P_e

ΔW_0 = foot-pounds of fluctuating energy as measured by one-half the total lobe areas enclosed by the crank-effort diagram per stroke

$W_0 = P_e \times \pi R$ = foot-pounds of effective work done per stroke, *i.e.*, mean engine turning effort P_e multiplied by the crankpin path during one stroke

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P_c = b.hp. × 550/V_0 = average crankpin force (in lb.) acting normal to the crankpin radius R, measured in feet.

HARMONIC-MOTION FORMULÆ

18 A sinuous crank effort, as measured with respect to the mean axis XX of Fig. 1, sets up a change in the synchronous velocity of the rotating-wheel parts within the limits $V_0 - v_0$ and $V_0 + v_0$, in accordance with the law of simple harmonic motion. The principles underlying such motion are easily established since the average ordinate of the sine-lobe area ΔW_0 bears a simple fixed relation to the maximum accelerating force P_0.[1]

[1] Starting with the general equation for accelerated motion,

$$a_0 = \frac{P_0}{m} \quad \ldots\ldots [3]$$

where

a_0 = maximum acceleration acting upon the mass m as measured in ft. per sec. per sec.

P_0 = maximum accelerating force in pounds, as measured at the middle of the sinuous crank-effort lobe.

Since the average ordinate under the sectioned sine lobe ΔW_0 is equal to $(2/\pi)\ P_0$, the maximum velocity increment will be

$$v_0 = \frac{2}{\pi} a_0 t_{\frac{1}{2}} \quad \ldots\ldots [4]$$

where

$t_{\frac{1}{2}}$ = time equivalent of one-half length of the sine lobe as measured in seconds, which in angular measure corresponds to $\pi/2$ radians.

The resulting maximum displacement being proportional to the average velocity change multiplied by time, it follows that

$$s_0 = \frac{2}{\pi} v_0 t_{\frac{1}{2}} = \left(\frac{2}{\pi}\right)^2 a_0 t_{\frac{1}{2}}^2 \quad \ldots\ldots [5]$$

where s_0 = maximum linear displacement or amplitude of oscillation (in ft.) resulting from a sinuous velocity change whose maximum is v_0.

As a further condition for simple harmonic motion, the maximum acceleration a_0 must be directly proportional to the displacement s_0, which expressed mathematically takes the convenient form

$$a_0 = \beta_0^2 s_0 \quad \ldots\ldots [6]$$

where β_0^2 = specific acceleration of the sinuous crank effort at unit displacement, as measured with respect to the synchronous reference position ZZ of Fig. 1.

For the critical value s_0 = 1 ft., the factor a_0 becomes equal to β_0^2; substituting this value in [5] and transposing, the following relation is obtained, which shows that the time period for harmonic motion is independent of its amplitude; thus,

$$t_{\frac{1}{2}} = \frac{\pi}{2\beta_0}; \quad t = \frac{\pi}{\beta_0}; \quad t_1 = \frac{2\pi}{\beta_0} \quad \ldots\ldots [7]$$

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19 When a body oscillates harmonically, the characteristic relations existing between the acceleration, velocity and displacement factors are definitely fixed by the basic constant β_0 as given in Equation [8].

20 Applying these deductions to the case of a sinuous crank-effort diagram for a single-cylinder engine, the time period of a complete oscillation is that required for one stroke, which is equal to

$$t_1 = \frac{60}{2N} = \frac{2\pi}{\beta_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots [9]$$

where N = revolutions per minute.

21 The corresponding basic value of the primary crank-effort constant β_0 may be found by substituting the above value of t_1 in Equation [7]; thus,

$$\beta_0 = \frac{2\pi}{30 \div N} = 0.21\,N \quad \ldots\ldots\ldots\ldots\ldots\ldots [10]$$

22 The other basic values required to characterize the harmonic wheel motion set up by a sinuous crank effort when making a complete oscillation in a time period of one stroke as per Eq. [9], may be found by substituting in Eq. [1]; thus,

$$v_0 = \frac{\Delta W_0}{2mV_0} = \beta_0 s_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots [11]$$

where $V_0 = 2\pi RN/60$ = mean crankpin velocity in ft. per sec.
v_0 = maximum velocity increment superimposed upon V_0
s_0 = corresponding maximum displacement (in ft.) as measured from the synchronous reference position ZZ.

23 For a single-cylinder engine the pitch length of its crank-effort lobe, *i.e.*, the space passed over by the crankpin in the time period of one-half stroke, is equal to $\pi V_0/\beta_0$, and since $(2/\pi)P_0$ represents the average accelerating force acting upon the crankpin during this period, then

$$\Delta W_0 = \frac{2}{\pi} P_0 \left(V_0 \frac{\pi}{\beta_0} \right) = \frac{2 P_0 V_0}{\beta_0} = 2 m V_0 v_0 \quad \ldots\ldots\ldots [12]$$

where $t_{\frac{1}{4}}$, $t_{\frac{1}{2}}$ and t_1 are the respective times of a quarter, half and complete period of harmonic oscillation.

It will be seen that the constant β_0 converts the time factor into angular or π measure. It also fixes other important characteristics of simple harmonic motion, as is evident from the following substitution in Equation [4]:

$$v_0 = \frac{2}{\pi} a_0 \left(\frac{\pi}{2\beta_0} \right) = \frac{a_0}{\beta_0} = \beta_0 s_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots [8]$$

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In a similar manner it will also be found that

$$\Delta W_0 = KW_0 = KP_c V_0 \frac{2\pi}{\beta_0} \quad \text{[13]}$$

24 For a single-cylinder engine the maximum velocity increment v_0 may be found in terms of known constants by substituting the above values in Eq. [11]; thus,

$$v_0 = \frac{2\pi KP_c V_0}{\beta_0} \cdot \frac{1}{2mV_0} = \frac{\pi KP_c}{m\beta_0} = \beta_0 s_0 \quad \text{[14]}$$

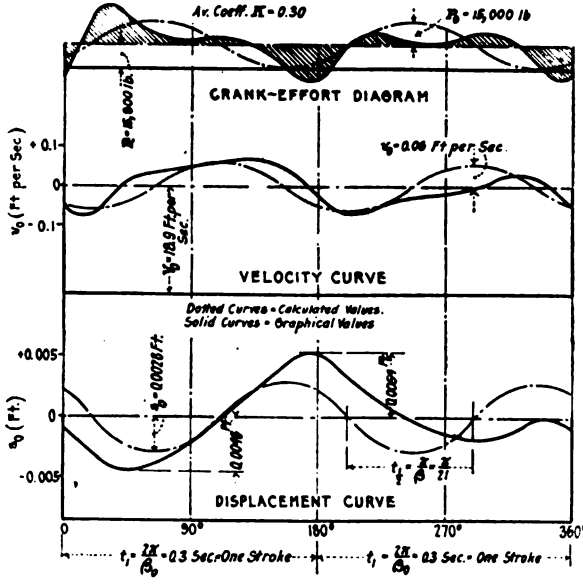

FIG. 2 CRANK-EFFORT DIAGRAMS FOR SINGLE-CYLINDER 500-B.HP. KOERTING GAS ENGINE

Cylinder dimensions, 25 × 43½ in.; speed, 100 r.p.m.; piston-rod diameter, 6½ in.; wheel weight at 17½ ft. outside diameter, 24,000 lb.; equivalent mass m at crankpin, 12,000 units; load condition, maximum

25 From the above it also follows that

$$P_0 = m\beta_0^2 s_0 = \pi KP_c \quad \text{[15]}$$

26 For a twin-cylinder engine the corresponding equations are

$$v_0' = \beta_0' s_0' \quad \text{[14a]}$$

$$P_0' = m(\beta_0')^2 s_0' \quad \text{[15a]}$$

where $\beta_0' = 2\beta_0$ when the crank-effort diagram is such that all the lobe-areas are substantially alike

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$= \frac{1}{2} \beta_0$ when the crank-effort lobes are sufficiently unbalanced as to require evaluation by the differential method of sine approximation.

27 Fig. 2 shows that the average results obtained graphically from an actual single-cylinder crank-effort diagram can readily be evaluated on the basis of the sine-curve approximation, and that the resulting average velocity and displacement increments may be

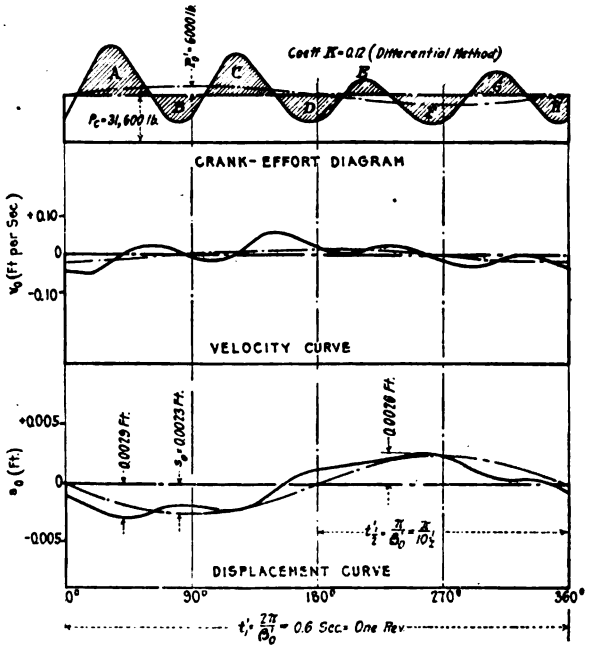

FIG. 3 CRANK-EFFORT DIAGRAMS FOR TWIN-CYLINDER 2 × 500-B.HP. KOERTING GAS ENGINE

Cylinder dimensions, 25 × 43½ in.; wheel weight at 17½ ft. outside diameter, 48,000 lb.; equivalent mass m at crankpin, 24,000 units; load conditions, maximum

determined with a fair degree of accuracy by means of the given equations. This figure represents a crank-effort diagram for a single-cylinder 500-b.hp. double-acting Koerting gas engine operating at maximum load. The specifications are given in detail in Fig. 2, the wheel in this case being exceptionally light at about 50 lb. per b.hp.

28 A corresponding diagram for a set of twin-cylinder engines of the same make and size is shown in Fig. 3. In both diagrams due

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allowance has been made for the inertia effect of the reciprocating parts, angularity of connecting rod, and the like.

29 Referring first to Fig. 2, the larger sectioned lobe areas in the first half of the crank-effort diagram of this single-cylinder engine are due mainly to the difference of the head- and crank-end piston areas, since these engines operate without tail rods.

30 Taking the coefficient of energy fluctuation K in the given formulæ as proportional to the arithmetical average value of the sectioned lobe areas shown in Fig. 2, the comparative results in Table 1 are obtained.

31 The calculated sinuous values are plotted as dotted lines in Fig. 2. For present purposes the average displacement increment $(2/\pi)s_0$ is of importance and the table shows its estimated value to be in fair agreement with the graphical result. Should a closer

TABLE 1 COMPARATIVE DISPLACEMENT VALUES FOR SINGLE ENGINE

Items	Estimated by Formulæ	Graphical Determinations
P_c	15,800 lb.	.....
β_0	21	.....
K	0.30	0.24 to 0.39
P_0	15,000 lb.	10,000 to 27,000 lb.
ΔW_0	27,000 ft-lb.	20,400 to 33,200 ft-lb.
$(2/\pi)v_0$ (avg. velocity)	0.038 ft. per sec.	0.041 ft. per sec.
$(2/\pi)s_0$ (avg. displacement)	0.0018 ft.	0.0021 ft.

estimate be desired, due allowance must be made for the difference in head-end and crank-end piston pressures.

32 In fact, accurate determinations of this kind require that each crank-effort curve be carefully inspected for best mode of treatment by sine-curve approximation. In the case of the particular twin-cylinder diagrams shown in Fig. 3, the four large head-end lobes lying in the left-hand half of the diagram so accentuate the unbalanced effect of the crank-effort forces as to dominate the time period of the resulting velocity and displacement curves. The total period of oscillation is thus increased to one revolution. Under these conditions the corresponding coefficient of energy fluctuation must be determined by the differential method, by which the equivalent excess lobe area of Fig. 3 becomes equal to

$$(A + C) - (B + D) = \Delta W_0' = (F + H) - (E + G)$$

On this basis the coefficient K' for the twin engine becomes equal to 0.12, the constant β_0' having a value of $\frac{1}{2}\beta_0 = 0.105\,N$.

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33 The specifications relating to the twin-cylinder engine are given in the diagram, from which the estimated value for the average displacement $(2/\pi)s_0'$ is found to be 0.00145 ft., as compared to 0.0015 ft. for the graphical determination.

34 In case the crank-effort diagram of a twin-cylinder engine is such that all the lobe areas are substantially alike, then the period of oscillation for the resulting velocity and displacement curves will practically coincide with that of the primary crank-effort curve, thus making β_0' equal to 2 β_0 instead of $\frac{1}{2}\beta_0$ as required when the differential method of sine approximation must be resorted to.

ARMATURE-DISPLACEMENT INCREMENTS FOR SINGLE NON-PARALLELED GENERATOR UNITS

35 It is to be borne in mind that the harmonic-motion formulæ thus far deduced apply only to the case of a reciprocating engine whose sinuous crank effort works against a *uniform* or straight-line resistance XX, such as would be encountered in a lineshaft drive and the like.

36 The resulting relation of velocity and displacement curves is indicated in Fig. 1. The maximum acceleration a_0, *i.e.*, rate of velocity change, is measured by the slope of line $R'S'$, and this occurs at a point directly under the maximum force P_0. According to Equation [8], $a_0 = P_0/m = \beta_0 v_0$, hence the time factor fixing the slope $R'S'$ is $1/\beta_0$. In a similar manner the maximum rate of displacement change as measured by the slope $R''S''$ becomes equal to $s_0/(1/\beta_0) = v_0$.

37 These simple relations may be materially modified when reciprocating engines are used to drive alternating-current generators, especially those connected in parallel. In that event the armature oscillations resulting from the irregular crank effort set up a periodic cross-current pull which is capable of producing a cyclic variation in the engine load. This reactive effect is dependent upon the characteristic behavior of the driven a.c. generator, the essential features of which are best represented graphically by means of vector diagrams as elucidated in the Appendix.

38 Touching upon the principles underlying electric-power generation by means of an alternator, it may be pointed out that such a generator running at synchronous speed can only deliver current to the bus bars when the armature is made to lead with respect to the neutral position assumed by the armature when running at no load. That is to say, the application of engine power forces the

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armature ahead of this neutral phase position by a certain angular-displacement lead such that it will still be running at synchronous speed but out of phase with its neutral phase position by an angular-displacement lead $+\alpha_0$. On the other hand, when an external resisting force causes the armature to lag with respect to the neutral phase position by an angle $-\alpha_0$, this reverse action will convert the machine into a synchronous motor.

39 As explained in the Appendix, the mean angular-displacement lead α_0 is dependent upon the construction characteristics of the alternator and serves as a measure of the full-load output delivered by this type of generator. Assuming the driving torque and output to remain constant, then the uniformly rotating armature will maintain a constant lead angle α_0 with respect to its neutral or no-load phase position. In case, however, the generator is driven by a reciprocating engine, its irregular crank effort will cause a periodic shift in the armature displacement equal to $\pm\alpha_x$, as measured with reference to the mean lead angle α_0.

40 Applying these deductions to the case of a *single* alternating generator driven by a reciprocating engine, the resulting speed fluctuation as measured by the coefficient δ_0 will cause the armature lead angle to vary within the limits $\pm\frac{1}{2}\delta_0\alpha_0$. This periodic shift in the armature lead angle α_0 serves to produce a corresponding change in the generator output. Hence the effect of varying the resistance against which the engine has to work may be embodied in its crank-effort diagram by substituting a sinuous curve for the straight base line XX of Fig. 1. As shown dotted, the phase and period of this new resistance curvefor a single-cylinder unit coincide with those of its primary displacement curve, while the amplitude of such initial armature oscillation may be fixed at $\frac{1}{2}\delta_0 P_c$, as plotted upon the reference line XX.

41 When working with respect to this new sinuous base line, the sectioned lobe area of Fig. 1 increases from ΔW_0 to $(1 + \frac{1}{2}\delta_0)\Delta W_0$, which naturally involves a corresponding increase in the primary velocity increment v_0 and the displacement s_0. It is evident that the resulting increment in armature displacement will, in turn, react upon the crank-effort force in a manner that will still further increase the excess lobe areas of the crank-effort diagram. An infinite series of such corrections is required to ascertain the ultimate displacement of the armature. The final angular-displacement shift is proportional to the excess lobe area measured with respect to the final position assumed by the dotted sinuous base line, and this area

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may readily be found by means of the following expression for the sum of a decreasing geometrical progression:

$$\Delta W_0' = \Delta W_0 \left\{ 1 + \frac{\delta_0}{2} + \left(\frac{\delta_0}{2}\right)^2 + \cdots \left(\frac{\delta_0}{2}\right)^n \right\}$$

42 The bracketed sum may be termed the "enlargement factor" and is equal to $1/[1 - (\delta_0/2)]$, or

$$\Delta W_0' = \Delta W_0 \left(\frac{1}{1 - \frac{\delta_0}{2}} \right) = \Delta W_0 \left(\frac{V_0}{V_0 - v_0} \right) \cdots\cdots\cdots [16]$$

43 The enlargement factor tends to increase the coefficient of energy fluctuation K as found for the primary crank-effort diagram, but since the ratio of v_0 to V_0 is necessarily small, this correction is of minor consequence.

44 Equation [16] is identical in form with some similar formulæ developed in the leading German literature relating to this subject, notably in the theories advanced by Rosenberg.[1] However, attention is called to the fact that in the present treatment Eq. [16] is intended to apply only to the case of a *single* alternating-current generator connected to independent bus bars, while in the foreign references this same equation is intended to cover the case of generators running in parallel on the assumption that the cross-current pull is responsible for this relatively small enlargement factor.

45 The vector diagrams of the Appendix show that it is unnecessary to resort to cross-current pull in order to explain this minor displacement increment, since a single alternator armature driven by a reciprocating engine is subjected to change in phase position which in itself is readily capable of setting up the relatively small periodic displacement variation required to satisfy Eq. [16].

46 The author is therefore led to conclude that the basic assumptions as to cross-current flow made in the cited foreign literature are untenable, a view that is substantiated by the accompanying experimental determinations, which show a far larger cross-current flow for paralleled generators than is indicated by any of the equations yet deduced.

CUMULATIVE DISPLACEMENT EFFECTS FOR PARALLELED GENERATOR UNITS

47 Turning now to the electrical conditions under which alternators operate in parallel, such armatures are no longer locked with

[1] Electrotechnische Zeitschrift, May 15, 1902. See also Zeitschrift des Vereines Deutscher Ingenieure, 1904, p. 793.

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the external circuit in the manner of a single generator; instead, the electrical tie assumes characteristics closely analogous to those of a flexible coupling acting between the two paralleled armature shafts, all of which is rather fully set forth in the Appendix.

48 The flexible nature of this coupling allows one of the paralleled armatures to lead periodically with respect to its mean lead angle α_0, provided the other armature simultaneously lags with respect to its α_0 by an approximately equal angular-displacement shift α_x. This difference in armature positions sets up an equalizing or cross-current flow between the generators whereby the lagging armature may momentarily generate less power than its mate without materially affecting the combined output delivered to the common bus bars.

49 The cross-current pull is, however, capable of superimposing oscillations of considerable magnitude upon the rotating armature. The amplitude of such oscillations is generally much larger than was found to be the case for the single generator connected to independent bus bars.

50 It will now be shown that this increment of displacement is due to the cumulative action which results in paralleled generators whenever the variable generator load, as fixed by the periodic cross-current pull, is combined with an uneven sinuous crank effort having a different period.

51 The resultant periodic armature oscillation produced by the combined action of two such forces, i.e., excess crank effort P_0 and cross-current pull P_{cc}, is likely to become cumulative when the period of the pull P_{cc} bears certain critical relations to the period of the force P_0.

52 As given by Eq. [A] of the Appendix, the factor P_{cc} as taken in terms of the mean crankpin force P_c is equal to

$$\frac{P_{cc}}{P_c} = \frac{\sin \alpha_x}{\sin \alpha_0} \cdot \cos \alpha_0$$

53 Owing to the relatively small angular armature displacements permissible in good practice, the mathematical treatment of this portion of the discussion may be much simplified by substituting angular measure for the sine values of the lead and shift angles α_0 and α_x, and by further assuming that the value of $\cos \alpha_0$ in the above equation may be taken as equal to unity without serious error. On the basis of this approximation, Eq. [A] reads

$$\frac{P_{cc}}{P_c} = \frac{\alpha_x}{\alpha_0} = \frac{s_x}{s_a}$$

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or

$$\frac{P_{cc}}{s_x} = \frac{P_c}{s_\alpha} = F = m\,\beta_x^2 \ldots\ldots\ldots\ldots\ldots\ldots [17]$$

where α_0 = mean angular-displacement lead of the armature as measured in electrical radians

α_x = angular-displacement shift of the armature as measured with respect to the mean lead position α_0

$s_\alpha = \alpha_0 R$ = arc length in feet, corresponding to the armature-displacement lead angle α_0 as measured at the crankpin circle

$s_x = \alpha_x R$ = arc length in feet, corresponding to the armature-displacement shift angle α_x.

54 In the above equation the constant F represents the specific accelerating force (in lb.) of the cross-current pull when the linear displacement $s_x = 1$ ft., as measured at the crankpin circle. Eq. [17] further shows that the cross-current pull P_{cc} may be taken as directly proportional to the linear shift s_x and that it becomes approximately equal to the mean engine turning force P_c when $s_x = s_\alpha$. The constant β_x fixes all of the characteristic relations of the harmonic armature movements resulting from the action of the cross-current pull except that of the amplitude limit.

55 Since the angles α_0 and α_x are measured in electrical radians, Eq. [17] may also take the form

$$\frac{F}{m} = \beta_x^2 = \frac{P_c}{m} \cdot \frac{n}{R\alpha_0} \ldots\ldots\ldots\ldots\ldots\ldots [18]$$

where β_x^2 = specific acceleration of the cross-current pull at $s_x = 1$ ft. linear armature displacement as measured at the crankpin circle

$\frac{\pi R}{n}$ = generator pole pitch as measured (in ft.) at the crankpin circle = π electrical radians

n = number of pole pairs = cycles per sec. $\times$ $(60/N)$.

56 The resulting cross-current pull corresponding to a given armature shift s_x is dependent upon the constructive characteristics of the generator, which are largely fixed by the value of s_α. Accordingly, the relation of the basic constants β_0 to β_x may also be expected to be dependent upon the factor s_α. For single-cylinder engines the numerical value for this relation may be arrived at as follows:

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57 Transposing Eq. [14] to the form

$$\beta_0^2 = \frac{\pi K P_c}{m s_0}$$

and dividing by Eq. [18], gives

$$\frac{\beta_0}{\beta_x} = \sqrt{\frac{\frac{\pi K}{s_0}}{\frac{n}{R\alpha_0}}} = \sqrt{\pi K \frac{s_\alpha}{s_0}} = 0.21\, N \sqrt{\frac{R\alpha_0}{n} \cdot \frac{m}{P_c}} \quad \ldots\ldots [19]$$

58 When $\beta_0' = \frac{1}{2}\beta_0$, the corresponding equation for twin-cylinder engines becomes equal to

$$\frac{\beta_0'}{\beta_x} = \sqrt{\frac{\pi}{2} K' \frac{s_\alpha}{s_0'}} = 0.105\, N \sqrt{\frac{R\alpha_0}{n} \cdot \frac{m}{P_c}} \quad \ldots\ldots [19a]$$

where K' = coefficient of energy fluctuation as determined by the differential method

s_0' = displacement increment as found from the crank effort on the basis of $t_{\frac{1}{2}}' = \pi/\beta_0$ = one stroke.

59 The above equations fix the vital relations required for cross-current determinations in paralleled generators; they show that the important ratio of the constants β_0/β_x is independent of the coefficient K, and secondly that this ratio is largely dependent upon the speed factor N.

60 Since the value of the primary displacement s_0 is usually quite small in comparison with s_α, the period of oscillation set up by the cross-current pull when acting alone is a relatively long one, being equal to

$$t_{\frac{1}{2}} = \frac{\pi}{\beta_x} \quad \ldots\ldots [20]$$

61 It will be seen that the paralleled armatures are acted upon by two distinct periodic forces, *i.e.*, excess crank effort and cross-current pull, whose time periods are π/β_0 and π/β_x, respectively. Each of these forces tends to set up independent oscillations, but they combine to swing the armatures in a resultant period which may be found by replacing the straight resistance line XX of the crank-effort diagram by a sinuous resistance or load curve having a relatively large amplitude equal to the cross-current pull P_{cc}, as indicated in Fig. 4.

62 In the case of paralleled generators the resultant sectioned lobe area of the crank-effort diagram is to be taken with respect to the resultant sinuous resistance line P_{cc}, since this area fixes the

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period and generally determines the character of the final armature movements.

63 Mathematical expressions for the area lying between any two sine curves of different periods and amplitude become involved, and hence for the sake of simplicity of treatment the tentative assumption will first be made that the cross-current pull will continue

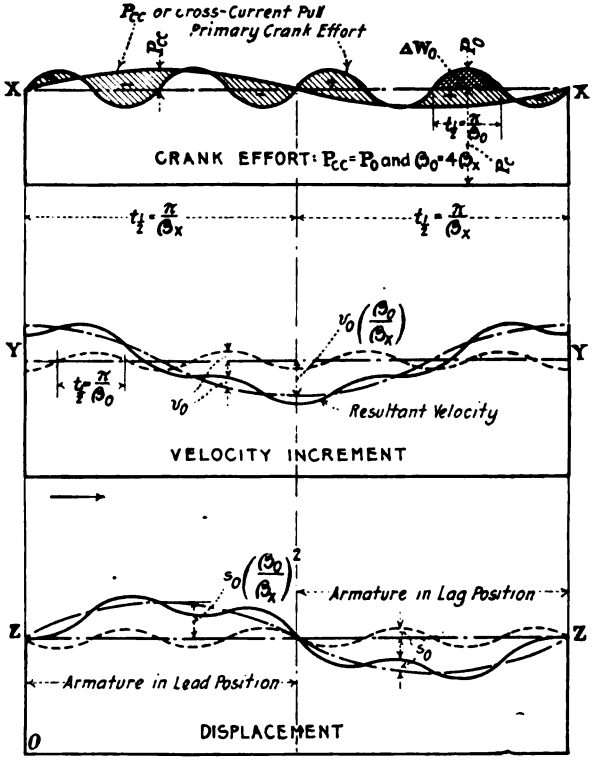

FIG. 4 DIAGRAM SHOWING CUMULATIVE EFFECT OF CROSS-CURRENT PULL FOR $\beta_0/\beta_x > 7/2$

to superimpose cumulative oscillations upon the rotating armature until the condition of indifferent equilibrium is finally reached where $P_{cc} = P_0$.

64 The consideration of this problem may be further simplified by taking into account only the two limiting conditions as to time of oscillation: namely, (1) the case in which the ratio of β_0/β_x is a relatively large one, i.e., 7/2 or over, by which assumption the period and amplitude of the cross-current pull is made to dominate and fix

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the character of the resulting armature movements as shown in Fig. 4; and (2) the case in which the factors β_0 and β_x are approximately equal, the effect of which is to produce a series of comparatively rapid armature oscillations whose amplitude rises and falls periodically in accordance with the sine law, as indicated in Fig. 5.

CASE I CUMULATIVE ARMATURE DISPLACEMENTS FOR $(\beta_0/\beta_x) > 7/2$

65 Taking up the first of these cases in detail and referring to Fig. 4, the average velocity change produced upon the armature

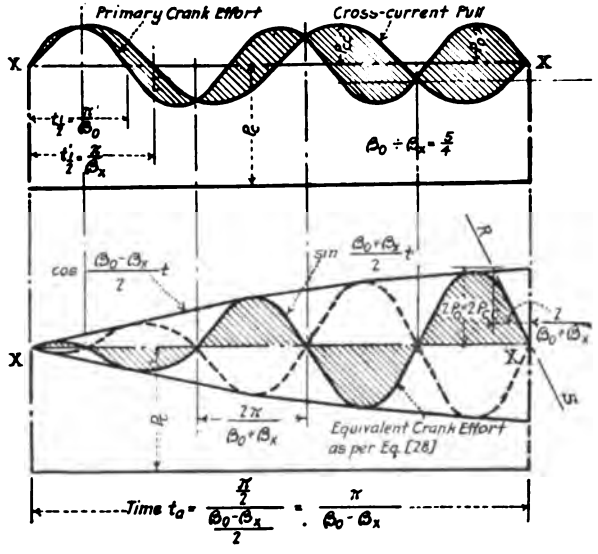

FIG. 5 DIAGRAM SHOWING CUMULATIVE EFFECT OF CROSS-CURRENT PULL FOR $\beta_0/\beta_x < 7/2$

and wheel parts will be a function of the resultant sectioned area lying between the crank-effort and the sinuous resistance or load curves. For the condition that $P_{cc} = P_0$, it will be apparent that the total area under one of the cross-current or P_{cc} sine lobes as measured with respect to its straight base line XX becomes equal to $(\beta_0/\beta_x)\,\Delta W_0$, i.e., equal to the sum of all the ΔW_0 lobe areas enclosed by the primary crank-effort curve in the time period π/β_x. If then such a cross-current pull were acting alone upon the armature parts, the energy absorbed during the time period $\pi/2\beta_x$ would, according to Eq. [4], impart a maximum velocity change equal to $(\beta_0/\beta_x)\,v_0$.

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This value serves to fix the amplitude of the fundamental velocity curve shown dotted and dashed in Fig. 4.

66 The cross-current pull when acting alone may be expected to set up armature oscillations closely following the laws of simple harmonic motion, because the accelerating force P_{cc} is approximately proportional to the displacement shift s_x. In addition to this motion, the irregularity of the crank effort sets up independent sinuous velocity changes of smaller magnitude as drawn dotted upon the axis YY, which superimposed upon the fundamental curve produce the resultant velocity shown by the full-lined curve of Fig. 4.[1]

67 According to Eq. [22], the maximum velocity increment attained by the armature when acted upon jointly by the equal excess

[1] The equation for motion of this character takes the general form

$$v = v_0 \frac{\beta_0}{\beta_x} \sin \beta_x t + v_0 \sin (t + t_0) \quad \ldots\ldots\ldots\ldots\ldots\ldots [21]$$

where v = velocity ordinate for the resultant wave curve at any time t
β_0, β_x = respective constants converting the time t into circular or π measure
t_0 = initial time shift fixing the phase relation of the crank-effort curve with respect to that of the cross-current pull.

When $t_0 = \pi/2\,\beta_0$, the second factor in this equation becomes equal to $\cos \beta_0 t$. In case the ratio β_0/β_x should equal a whole number plus a fraction, this will cause a periodic change to occur in the value of t_0, the effect of which is to introduce a creeping value in the second factor of the equation. However, such a change has but a negligible effect upon the average armature-displacement shift, and for present purposes t_0 may be set equal to zero.

Velocity change, as shown by Equation [1], is a direct measure of energy fluctuation. Accordingly, the sum total of the sectioned area of the crank-effort curve shown in Fig. 4 must bear the same relation to the area under the fundamental P_{cc} sine curve as measured with respect to the base line XX that the area under the resulting velocity curve (drawn full-lined) bears to its fundamental v_0 sine curve (drawn dotted and dashed) when measured with respect to the base line YY.

This relation is readily found in the case of the velocity curves by integrating Eq. [21] between the following limits:

$$\text{Area} = v_0 \frac{\beta_0}{\beta_x} \int_0^{\pi/\beta_x} \sin \beta_x t \cdot dt + v_0 \int_0^{\pi/\beta_0} \sin \beta_0 t \cdot dt = 2\, v_0 \frac{\beta_0}{\beta_x} \left(\frac{1}{\beta_x} + \frac{1}{\beta_0} \right)$$

Dividing this area by the lobe length π/β_x and multiplying the resulting mean velocity by $\pi/2$, we have

$$v_x = v_0 \left(\frac{\beta_0}{\beta_x} + 1 \right) = v_0 \frac{\beta_0}{\beta_x} \left(1 + \frac{\beta_x}{\beta_0} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots [22]$$

where v_x = maximum change in velocity attained by the armature at the instant when the displacement shift $s_x = 0$.

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crank-effort and cross-current-pull forces, will be $[1 + (\beta_x/\beta_0)]$ greater than $v_0 (\beta_0/\beta_x)$, which latter is the velocity increment that the cross-current pull could produce when acting alone.

68 The corresponding maximum linear armature-displacement shift resulting from the combined action of the cross-current pull and irregularity of crank effort, becomes equal to

$$s_x = \frac{v_x}{\beta_x} = s_0 \left(\frac{\beta_0}{\beta_x}\right)^2 \left(1 + \frac{\beta_x}{\beta_0}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [23]$$

by Eq. [19] $= \pi K \overset{\circ}{s}_a \left(1 + \frac{\beta_x}{\beta_0}\right)$ for a single-cylinder engine

by Eq. [19a] $= \frac{\pi}{2} K' s_a \left(1 + \frac{\beta_x}{\beta_0'}\right)$ for a twin-cylinder engine when $\beta_0' = \frac{1}{2}\beta_0$

69 As applied to the crank-effort diagram, the above deductions show that when P_{cc} finally reaches the limiting value of P_0, by cumulative action, the maximum armature velocity increment is proportional to all of the energy area enclosed by the fundamental P_{cc} sine lobe, i.e., $W_0 (\beta_0/\beta_x)$, plus one of the primary crank-effort lobes ΔW_0, as measured with respect to the base line XX.

70 Equation [23] fixes the actual limiting displacement shift s_x that may be expected when two paralleled alternators have settled into equilibrium as regards the interchange of cross-current energy. The above deductions were based upon the tentative assumption that the cumulative armature oscillations would continue until the pull P_{cc} became equal to the force P_0. Proof that the armatures do reach a state of indifferent equilibrium when oscillating under this condition is presented below.[1]

[1] Equation [20] determines the time period of the harmonic oscillation resulting from the cross-current pull when acting alone. This period is independent of the amplitude of oscillation so long as the specific acceleration F/m as defined by Eq. [17] remains constant. Under this condition the armature, after being released from any given displacement position, will invariably attain a certain fixed velocity increment at the instant of crossing its central position for which $\alpha_a = 0$. If then the introduction of a disturbing force, such as irregular crank effort, acts in combination with the cross-current pull, this will effect an increase in both the velocity and amplitude of the original oscillation set up by the cross-current pull.

The degree of disturbance introduced by the excess crank-effort forces is dependent upon the net sectioned area lying between these two periodic curves when plotted upon a common diagram as indicated in Fig. 4. When the ratio of the cross-current pull p_{cc} to the excess effort P_e is less than unity, this area as found by a series of graphical determinations may be taken as a function of $(p_{cc}/P_e)^2$;

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71 As deduced from Equation [23], the corresponding mean shift angle $\alpha_{x_{av}}$ measured with respect to α_0 becomes approximately equal to

$$\pm \alpha_{x_{av}} = \frac{2}{\pi} \frac{s_0}{R} \left(\frac{\beta_0}{\beta_x}\right)^2 \left(1 + \frac{\beta_x}{\beta_0}\right) = \frac{2}{\pi} \alpha_x \left(1 + \frac{\beta_x}{\beta_0}\right) \ldots\ldots\ldots [26]$$

This angle $\alpha_{x_{av}}$ is fixed by the average ordinate of the sectioned area lying between the crank effort and the sinuous load curve as indicated in Fig. 4.

72 The correctness of the above deductions has been checked by means of actual cross-current measurement tests conducted upon

accordingly, the resultant velocity increment acquired at the instant of passing the central position may be expressed approximately as

$$v_{x1} = v_0 \frac{\beta_0}{\beta_x} \left\{1 + \frac{\beta_x}{\beta_0} \left(\frac{p_{cc}}{P_0}\right)^2\right\} \ldots\ldots\ldots\ldots\ldots\ldots [24]$$

where p_{cc} = cross-current pull less than $P_{cc} = P_0$.

For small values of p_{cc}/P_{cc} the velocity increment v_{x1} is considerably larger than would be set up were the cross-current pull p_{cc} acting alone. If to this were added the velocity increment v_0 produced by the uneven primary crank effort when acting alone, the sum of these two velocities would still not exceed

$$v_{x2} = v_0 \frac{\beta_0}{\beta_x} \left\{\frac{p_{cc}}{P_0} + \frac{\beta_x}{\beta_0}\right\} \ldots\ldots\ldots\ldots\ldots\ldots [25]$$

Comparing the bracketed portions of Equations [24] and [25], the numerical values of the first equation exceed those of the second for all values of p_{cc}/P_0 less than unity. It appears, therefore, that as soon as the uneven crank effort but slightly moves any one of the paralleled armatures out of its mean angular position, the corresponding periodic load change produced by the cross-current pull will modify the sectioned area of the combined crank-effort diagram so as to set up a resultant velocity increment which is larger than that given by Eq. [25]. That is to say, immediately after two alternators have been thrown into parallel, the primary crank-effort displacement s_0 will set up an initial cross-current pull sufficiently large to impart to the armature a small fundamental p_{cc} oscillation in a period π/β_x. Thereafter the resulting velocity increment v_{x1} produced by the combined action of this initial sinuous cross-current pull and the irregular crank effort will continually increase by cumulative action until the mature oscillations finally reach an amplitude such as will establish the critical relation $p_{cc} = P_{cc} = P_0$.

Should the pull P_{cc} be further increased with respect to the force P_0, the velocity increment determined by Eq. [24] will no longer exceed that of Eq. [25], from which it may be concluded that the interchange of cross-current energy will then have reached a state of indifferent equilibrium. There being no further tendency to force the armatures apart, they will therefore continue to oscillate in the prescribed amplitude limits of $P_{cc} = P_0$, as shown in Fig. 4.

The indifferent state of equilibrium finally reached by the oscillating armatures is such, however, that any disturbance in the relations of the external force as may be due to improper governor action and the like, may readily cause an increase in the average displacement between the paralleled armatures.

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a set of single-cylinder 500-b.hp. Koerting gas engines having heavy flywheels and driving three-phase alternators on an induction-motor load.

73 The crank-effort diagram for these engines is almost identical with that given in Fig. 2, and while the load was somewhat lighter, the coefficient of energy fluctuation may still be taken at its former value of $K = 0.30$. The comparative results attained with these two similar units running at a practically constant load, are given in Table 2.

TABLE 2 COMPARATIVE VALUES FOR SINGLE-CYLINDER ENGINES ($\beta_0/\beta_z = 6.4$)

SPECIFICATIONS	
Type of engine	Double-acting two-stroke Koerting gas-engine without tail rod
Cylinder dimensions	25 x 43½ in.; speed, 100 r.p.m.
Average engine load	425 b.hp. (about)
Piston-rod diameter	6½ in.
Weight of flywheel	73,000 lb. at 18 ft. O. D.
Total mass m	38,600 units at $R = 1.8$ ft.
Coefficient δ_0	1/660
P_0 at $K = 0.30$	11,700 lb. $= 0.95\ P_e$
Cos ϕ_0 in external circuit	0.73 (about)
Lead angle α_0	14½° (about) $= 0.255$ elec. radian
n at 25 cycles per sec	15 pole pairs
RESULTS	
Displacement s_0 by Eq. [14]	0.00068 ft.
β_z by Eq. [19]	3.3 for $\beta_0 = 21$
Ratio β_0 to β_z	6.4
Displacement shift s_z by Eq. [23]	48 s_0 (about)
Shift angle $\alpha_{z_{av}}$ by Eq. [26]	0.7 α_0
Ratio Z by Eq. [C]	1.08
Do., by test measurement	1.065
Cross-current I_{cc} by Eq. [B]	0.51 I_0

74 This table substantiates the author's contention relative to the Rosenberg theory, since it shows the resulting displacement shift s_z which is set up by the combined action of the cross-current pull and excess crank-effort force to be about 48 times as large as the primary displacement s_0 produced by the irregular crank effort when acting alone.

75 The relatively small difference in the estimated and test value of Z given in the above table may be accounted for in part by

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the dampening action of the generator pole shoes. On the basis of the above results, such shoes appear to be effective in the proportion of $(0.08 - 0.065)/0.08$; that is, in the present case the shoes appear to reduce the amplitude of the armature oscillations by about 19 per cent.

76 The pulsations recorded by the ammeter readings, as measured from maximum to maximum, showed 35 to 38 beats per min. as against an estimated period for such beats of $2\pi/\beta_x = 1.9$ sec., or about 32 beats per min.

77 The tested units were running on a fairly constant factory load and operated well in parallel. Accordingly, it may be concluded that under similar conditions the angular-displacement shift α_{x_m} could readily be increased to the full lead angle α_0 as a limiting value, without encountering any serious difficulty from excessive cross-current flow, or otherwise.

CASE II CUMULATIVE DISPLACEMENTS FOR $(\beta_0/\beta_x) < 7/2$

78 The foregoing formulæ for the displacement shift angle α_x were based upon the condition that the ratio β_0/β_x shall not fall below the critical value 7/2. At this juncture the time periods of the crank-effort and of the generator-load curves become more nearly equal, and as a result the combined or resulting sectioned area lying between these curves assumes an essentially different character from that shown in Fig. 4. The armature movements which take place when the ratio of β_0/β_x is relatively small are still found to act cumulatively until the cross-current pull p_{cc} reaches its critical value P_0, but the effect produced is a series of rather rapid armature oscillations which periodically rise and fall in amplitude as indicated in Fig. 5. In order that such armature movements may occur without giving up energy to the external power circuit, one of the paralleled armatures must lead at approximately the same instant that its mate lags, in the manner shown respectively by the full- and dotted-lined oscillations in the lower crank-effort diagram.

79 The equation for any ordinate P_x of the sectioned area lying in the upper crank-effort diagram of Fig. 5 takes the following form:

$$P_x = P_0 (\sin \beta_x t + \sin \beta_0 t) \ldots\ldots\ldots\ldots\ldots [27]$$

Combining the factors of this equation on the basis of the trigonometrical relation for the sum of sine values,

$$P_x = 2 P_0 \left(\sin \frac{\beta_0 + \beta_x}{2} \cos \frac{\beta_0 - \beta_x}{2} t \right) \ldots\ldots\ldots [28]$$

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80 This equation, as graphically analyzed in the lower crank-effort diagram, shows that the component oscillations as fixed by the sine factor vibrate cumulatively within the limit line fixed by the cosine factor. The time period of the component oscillation is determined by the mean value of β_0 and β_x, while the period of the limit line is fixed by their difference. The characteristics of the resulting velocity and displacement curves will be identical with those of the equivalent crank-effort curve shown in the lower diagram.

81 As indicated, the number of the component sine lobes enclosed within a half cosine lobe length is proportional to the respective period of the cosine and sine curves, thus,

$$\frac{\frac{\pi}{\beta_0 - \beta_x}}{\frac{2\pi}{\beta_0 + \beta_x}} = \frac{1}{2}\frac{\beta_0 + \beta_x}{\beta_0 - \beta_x} \quad \ldots\ldots\ldots\ldots\ldots\ldots [29]$$

82 The number of component lobes will therefore be equal to unity when $\beta_0 = 3\,\beta_x$. From this it follows that the mode of oscillation indicated in Fig. 5 may be expected to occur whenever the ratio of β_0 to β_x is less than 3, while for intermediate values lying between 3 and 4 the character of the resulting oscillations is only vaguely defined.

83 The time required for the cumulative oscillations to change from minimum to maximum amplitude is equal to

$$t_a = \frac{\pi}{\beta_0 - \beta_x} \quad \ldots\ldots\ldots\ldots\ldots\ldots [30]$$

which holds good for all values of β_0/β_x less than 3 and greater than unity. The maximum velocity increment attained by the wheel parts due to the accumulation of energy cannot at any time exceed the energy equivalent of the sectioned area as fixed by the largest one of the $\sin\frac{\beta_0 + \beta_x}{2}$ lobes, shown in Fig. 5. The corresponding maximum acceleration is limited to $2\,P_0/m$, and since the resulting velocity is proportional to $1/(\beta_0 + \beta_x)$ and not to $1/(\beta_0 - \beta_x)$, it will be seen that even for long periods that accompany small differences of β_0 and β_x the cumulative energy does not under any conditions tend to produce an infinite armature deflection. This point is brought out because Bonte,[1] among others, has advanced contrary views as based upon the Rosenberg theory previously discussed.

[1] Zeitschrift des Vereines Deutscher Ingeniure, Aug. 25, 1906, p. 1365.

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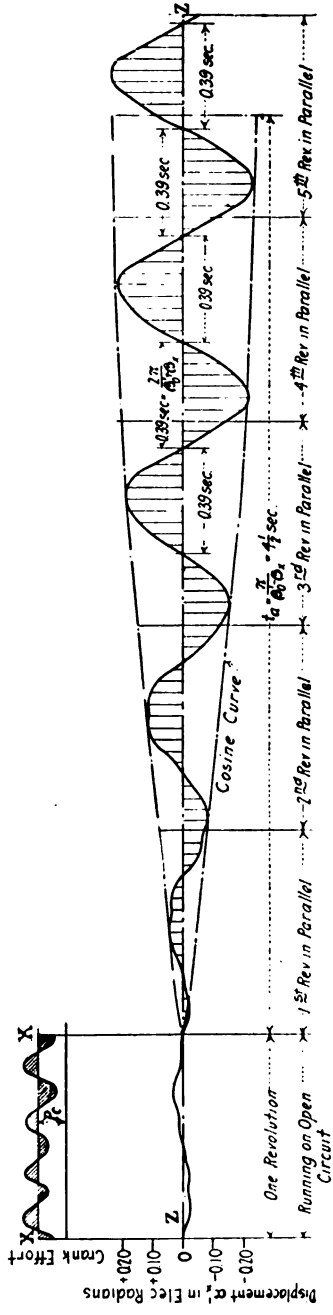

FIG. 6 GRAPHICAL DETERMINATION OF CUMULATIVE ARMATURE OSCILLATIONS FOR $\beta_0/\beta_2 = 1.09$

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84 As regards the value of the maximum to the average acceleration for values of β_0/β_x less than 7/2, this may be deduced from the following considerations: The area of the sectioned portion of Fig. 5 included within all of the component sin $\frac{1}{2}(\beta_0 + \beta_x)$ lobes, is equal to $2/\pi$ of the area enclosed by the limit line cos $\frac{1}{2}(\beta_0 - \beta_x)$, hence the mean ordinate of all the sectioned area becomes equal to

$$P_{0_{av}}' = \left(\frac{2}{\pi}\right)^2 \cdot 2P_0 = \left(\frac{2}{\pi} P_0\right)\frac{4}{\pi} \quad \ldots\ldots\ldots\ldots [31]$$

85 The cumulative force acting to oscillate the armature gradually builds up until it reaches a value of $2P_0$, which maximum force is $(\pi/2)^2$ larger than the average force. The constant $4/\pi$ in Eq. [31] corresponds to the factor $\left(1 + \frac{\beta_x}{\beta_0}\right)$ of Eq. [26], and for the usual range of wheel weights this factor is practically equal to $4/\pi$. The bracketed factor reaches this critical value when β_0 becomes equal to $3.6\,\beta_x$. It may be assumed, therefore, without serious discrepancy, that those equations deduced for the conditions represented by Fig. 4 hold true approximately for all values of β_0 greater than $(7/2)\beta_x$, while the latter equations intended to apply to Fig. 5 hold good for all values of β_0 less than $(7/2)\beta_x$.

86 For the cumulative oscillatory movements indicated by Fig. 5 the maximum angular-displacement shift cannot exceed

$$\alpha_x' = \frac{2P_0}{P_c}\alpha_0 = \frac{2P_0}{P_c} \cdot \frac{s\alpha n}{R} \quad \ldots\ldots\ldots\ldots [32]$$

87 The measured cross-current flow is determined by the average armature-displacement shift, and while α_x' for Case II is approximately twice as large as α_x as found for Case I, the average shift is almost identical with that given by Eq. [26], as is evident from the following relation:

$$\alpha_{x_{av}}' = \frac{2P_0}{P_c}\alpha_0\left(\frac{2}{\pi}\right)^2 = \frac{2}{\pi}\left(\frac{\alpha_x'}{2}\right)\frac{4}{\pi} \quad \ldots\ldots\ldots\ldots [33]$$

88 The deductions embodied in the last two equations have been checked by the graphical determinations shown in Fig. 6, as based upon the assumed specifications noted below. These curves were kindly worked out for the author some years ago by Mr. Erich C. Rassbach.[1] At that time the present mathematical basis had not yet been developed, and in order to determine the probable course of the resultant armature oscillations for small values of β_0/β_x, it became necessary to resort to a tedious graphical solution. The

[1] Sibley College Thesis, 1906.

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method pursued was one of finding the successive crank-effort, velocity, and displacement curves for each 10-deg. interval, and by continued assumption and inspection as to the probable course of the next following increment of these curves it was finally possible to obtain the desired results. The comparative figures given in Table 3 show satisfactory agreement.

TABLE 3 COMPARATIVE VALUES FOR TWIN ENGINES ($\beta_0/\beta_x = 1.09$)

ASSUMED SPECIFICATIONS	
Type of engine	Twin-cylinder double-acting two-stroke gas engine with tail rod
Cylinder dimensions	38 x 66 in.; speed, 80 r.p.m.
Piston-rod diameter	10 in.
Assumed load	4000 b.hp. = max. capacity
Moment of inertia of wheel	$\frac{113{,}000 \text{ lb.}}{32} \times 9.65 \text{ ft.}^2$
Total mass m	43,500 units at $R = 2.75$ ft.
K' by differential method	0.072
P_θ from crank-effort curve	48,000 lb. = 0.48 P_e
Lead angle α_0	about 16½° = 0.29 elec. radian
n	20 pole pairs
β_0'	0.105 N = 8.4

RESULTS	Calculated by Formulæ	Graphical Determinations
$(2/\pi)\, v_0'$ when $K' = 0.072$	0.02 ft. per sec.	0.026 ft. per sec.
$(2/\pi)\, s_0'$ when $K' = 0.072$	0.0027 ft.	0.0022 ft.
β_x by Eq. [19a]	$7.7 = \beta_0'/1.09$	.....
$\pi/(\beta_0' - \beta_x)$ by Eq. [30]	4½ sec. = 6 rev.	about 5½ rev.
Angle α_x' by Eq. [32]	$0.96\, \alpha_0$	About $0.85\, \alpha_0$
Angle $\alpha_{x_{av}}'$ by Eq. [33]	$0.37\, \alpha_0$	.....
Displacement shift s_x'	About $9\, s_0'$	About $8\, s_0'$
$2\pi/(\beta_0' + \beta_x)$	0.39 sec.	0.39 sec.

89 The method used as a basis for the graphical determinations of Fig. 6 was found to be so tedious as to make it utterly impracticable for commercial work. The present mathematical treatment allows the results to be much more promptly predetermined and offers the additional advantage of giving an oversight as to the effect which any contemplated change may be expected to produce.

90 The principles underlying the formulæ herein developed may also be used in solving the more general problems relating to

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cumulative oscillatory movements, such as are involved in hunting rotary converters and the like.

CONCLUSIONS

91 On the basis of the principles enunciated it may be concluded that when two alternators are thrown into parallel, the resulting cross-current flow, as measured by means of ammeters, will be largely independent of the wheel weight used, except in so far as this weight may influence the character of the regulation rendered by the governor.

92 The difficulty that may be involved in the use of a light flywheel resides in the detrimental secondary effects that may arise. When the ratio of β_0/β_x is less than 7/2, as is likely to be the case when using a light wheel, the oscillatory peak movement indicated in Fig. 5 becomes about twice as large would be produced by the use of a heavy wheel operating under conditions represented by Fig. 4. This difference in maximum angular-displacement shift may become so marked that the armature working with a relatively light wheel may be thrown far over into the negative or motor position. Such excessive shift in the armature displacement may readily create serious electrical disturbance, for should the angle α_x' plus α_0 at any time exceed $\pi/2$ electrical radians, i.e., one-half pole pitch, the paralleled generators would immediately fall out of step.

93 The best results in parallel operation may, therefore, be expected when the ratio β_0/β_x is kept as high as 6 or possibly 8. As is evident from Eqs. [19] and [19a], this condition is more readily complied with in the smaller short-stroke engines running at a relatively high speed. However, in order to avoid excessively heavy wheels for the long-stroke, slow-speed engines, it is found advisable to keep the wheel weight in a constant relation to the engine output.

94 For large double-acting four-stroke gas engines driving 25-cycle alternators, the total wheel weight when running at approximately 6000 ft. per min. peripheral speed is commonly taken at about the following values:

Single-cylinder units: about 100 lb. per b.hp. on producer-gas rating

Twin-cylinder units: about 75 lb. per b.hp. on producer-gas rating.

95 It is customary to increase the above constants by about 25 per cent for 60-cycle operation, in which case the wheel generally assumes very massive proportions for large slow-speed engines.

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96 The foregoing deductions do not take into account any beneficial effects which dampening coils and like devices may be able to exert upon the cumulative armature oscillations. The purpose of the present investigation was simply to find the most favorable inherent conditions when operating without compensating adjuncts of any kind.

The formulæ given are further conditioned upon identical constructive characteristics for all the paralleled engine and generator units. Any important difference in this respect may involve a considerable increase in the minimum expected cross-current flow as fixed by the given formulæ.

97 In case of unequal excitation the angular-displacement lead angle α_0 will not be the same in both paralleled generators, and this naturally involves an increased cross-current flow. The armatures may also be subject to a somewhat similar displacement shift due to a difference in the regulation characteristics of the engine governors, the effects of which may become especially pronounced during periods of sudden load change. In case furnace- or producer-gas engines are supplied with gas that is subject to frequent change in heating value, this also may seriously affect the regulation of the engine governor.

98 Finally, attention is called to the need of properly selecting the coefficient of speed fluctuation for the engine governor. The extent to which the primary speed coefficient may be increased by the cumulative displacements arising in paralleled engine units is indicated by the ratio of s_z/s_0 as given in Tables 2 and 3. The governor characteristics should be such that this increased "factor of irregularity" will not throw the governor gear into resonant oscillation with the cumulative wheel period.

99 Such a tendency may, to some extent, be counteracted by the use of suitable dampening coils for the generator pole pieces or by means of a governor dashpot and like expedients, but should the hunting tendency of the governor still persist, this may set up periodic variations in the engine's steam or gas supply. In case such action is allowed to reach considerable proportions it throws the armatures into oscillations of such violence as to make it difficult, if not impossible, to keep the alternators in parallel.

100 The use of additional wheel weight is able to effect an important change in the period of the cumulative wheel swing, and this, in turn, may make it far easier to meet the governing requirements. On the whole, therefore, it may be concluded that owing

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to the beneficial secondary effects the most satisfactory results in the parallel operation of reciprocating-engine units are to be attained by the use of reasonably heavy flywheels, as prescribed.

101 The author desires to express his indebtedness to Prof. C. D. Albert, of Cornell University, for reviewing the manuscript of this paper and for the helpful criticisms which he has made.

APPENDIX

A. C. GENERATOR VECTOR DIAGRAMS

102 Let E_x = open-circuit or no-load voltage of the alternator, i.e., the e.m.f. induced in the armature coils by cutting the effective magnetic flux set up by the d.c. field excitation
ir = ohmic drop due to armature resistance
ix = inductive drop due to armature reactance
e_0 = combined armature drop due to armature impedance
E_t = resulting full-load armature terminal voltage, this being the vector difference of E_x and e_0
I = full-load armature current per phase.

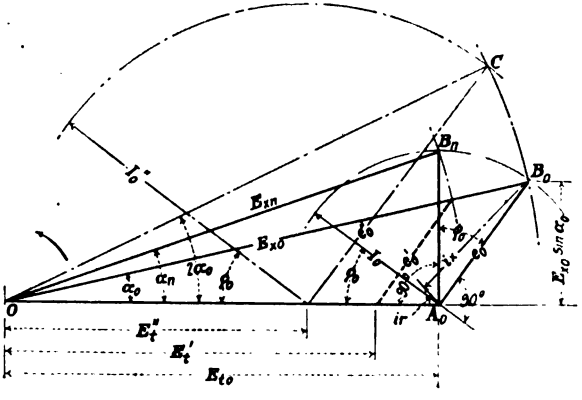

FIG. 7 VECTOR DIAGRAM FOR SINGLE A. C. GENERATOR

103 The characteristic behavior of an alternating-current generator may be set forth by the aid of the vector diagram, Fig. 7, in which the vector lengths may be taken to represent either instantaneous maximum values or their proportional mean values as measured by an a.c. ammeter or voltmeter.

104 As a standard of reference for time, the synchronous speed V_0 may be chosen, assuming this to represent the armature as rotating uniformly while in its open-circuit or neutral position, for which the angular-lead displacement α_0 is equal to zero.

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105 If then the application of full-load engine power forces the armature ahead, it will still be running in unison with the synchronous speed but will be shifted out of phase with it by the displacement lead angle α_0. This condition arises when the external generator circuit is closed. As a result, the full-load current I_0 flows through the armature and this sets up an inductive drop equal to the pressure vector length e_0, as shown in the diagram, Fig. 7.

106 For present purposes the armature resistance drop ir may be taken as negligible in comparison with the inductive drop ix. Accordingly, the alternating current in the armature would flow in approximate quadrature with the pressure vector e_0. In the case of the vector triangle OA_0B_0, the current I_0 would, therefore, lag by the phase angle ϕ_0 as measured with respect to the terminal voltage E_{t0}.

107 The vector lengths E_{t0}, E_{x0} and e_0 are interdependent, since the characteristic behavior of an a.c. generator invariably requires the respective vector lengths to be such as will form a closed triangular diagram.

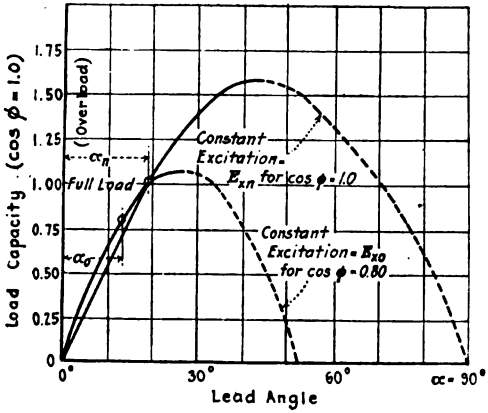

FIG. 8 CHARACTERISTIC BEHAVIOR OF A. C. GENERATOR

108 The triangle OA_0B_n of Fig. 7 represents conditions for a fully loaded generator connected to a non-inductive external circuit for which the power factor $\cos\phi = 1$, while the triangle OA_0B_0 represents the same generator working on an inductive motor load having a power factor of $\cos\phi = 0.8$. Assuming that it is desired to maintain a constant armature current I_0, i.e., that the vector e_0 remains constant, then the diagram shows that the excitation vector E_{xn} must be increased to E_{x0} in order to maintain a constant terminal voltage E_{t0} when changing the external power factor from $\cos\phi = 1$ to $\cos\phi = 0.8$.

109 On the other hand, should an alternator have its excitation set at E_{xn} for full non-inductive load, and if then the external power factor is changed to $\cos\phi = 0.8$, the armature current drops to e_0' at a terminal pressure equal to E_t', as indicated in the diagram, Fig. 7. The difference $E_{x0} - E_{xn}$ measures the resulting demagnetizing effect that the armature exerts upon the field flux.

110 The diagram further affords means for determining the output of the generator with change in the lead angle α_0. If, for instance, under usual conditions of constant excitation E_{x0} and a fixed external power factor ϕ_0, the load

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change should become such as to increase the angular-displacement lead to 2 α_0, then the current vector would be enlarged to I_0'' while the terminal pressure drops to E_t'', as indicated by dotted-and-dashed lines. The curves plotted as Fig. 8 have been derived on this basis and they show the manner in which the overload capacity of an alternator is dependent upon the lead angle α.

111 The area enclosed by any vector diagram is proportional to the electrical output of the alternator, as is apparent from the following relations deduced for the triangle OA_0B_0, Fig. 7:

$$\text{Power per phase} = E_{t0}I_0 \cos \phi_0 = E_{t0}\frac{e_0}{C}\cos\phi_0 = (E_{z0}\sin\alpha_0)\frac{E_{t0}}{C}$$

where C = constant or impedance of the armature circuit.

112 As regards the ratio of the vector lengths E_{t0} to e_0, this is fixed by the armature impedance. Taking I_0 to represent the full-load current per phase, then

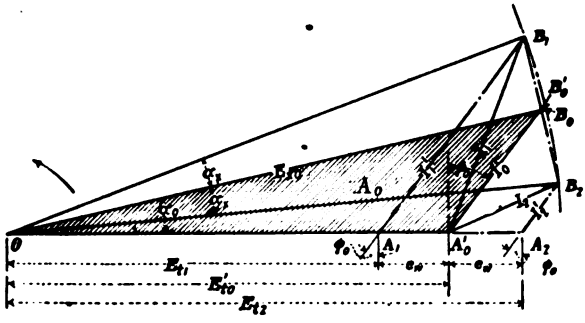

FIG. 9 VECTOR DIAGRAM FOR TWO A. C. GENERATORS PRIOR TO PARALLELING

e_0 is the pressure required to drive this current through the armature. Conversely, if the armature were standing still and the full-load pressure E_{t0} were applied at the terminals, then the resulting current flow would be $(E_{t0}/e_0)I_0$. In a similar manner the short-circuit current flow, which is determined by the excitation vector E_{zn}, becomes equal to $(E_{zn}/e_0)I_0 = I_s$.

113 This important constant fixes the basic angle α_n of Fig. 7, and thus determines the characteristic behavior of an alternating-current generator. For usual constructive proportions and for the excitation set at E_{zn} for non-inductive full load, the ratio $I_s/I_0 = E_{zn}/e_0$ may be taken as equal to approximately 3. Accordingly, $\sin \alpha_n = 0.33$, which fixes the lead angle α_n at about 19½ deg. The relation of α_0 to α_n for a change in the phase angle ϕ is apparent from the diagram.

VECTOR DIAGRAMS APPLIED TO PARALLEL RUNNING

114 In paralleled units the mean lead angle α_0 of the two armatures is still definitely fixed by the external load conditions, and the mean position assumed by the current vector must be in phase with the external phase angle ϕ_0. The flexible connection between paralleled armatures does, however, momentarily allow one of the armatures to shift forward by an angular displacement $+\alpha_s$ as measured with respect to the mean lead angle α_0, provided this shift is compensated for by a corresponding backward shift $-\alpha_s$ on part of the other armature.

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115 This condition is represented graphically by the vector diagram, Fig. 9, in which the two oscillating armatures are shown as being shifted out of their mean lead position α_0 by a maximum displacement increment $\pm\alpha_s$, respectively.

116 The electrical effect of paralleling two alternators may be traced most readily by first considering conditions as they exist just prior to throwing the generators into parallel. On this supposition the vector diagram, Fig. 9, may be taken to represent two equally excited alternators connected to independent external circuits but each working with the same power factor ϕ_0.

117 Under these conditions the load carried by the leading generator will be proportional to the larger triangle OA_1B_1, while the lesser load upon the lagging generator will correspond to the smaller triangle OA_2B_2. Using the respective armature-drop vectors as a measure of current flow, it will be seen that prior to parallel connection the current flowing out of the leading armature is equal to I_1' at a terminal pressure E_{t1}, while the corresponding values for the lagging armature are I_2' and E_{t2}.

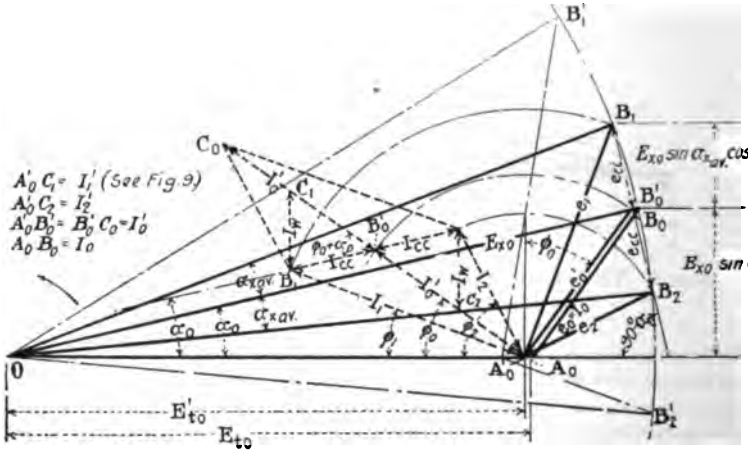

FIG. 10 VECTOR RELATIONS FOR TWO A. C. GENERATORS AT INSTANT OF PARALLELING

118 If then the alternators are properly synchronized and thrown into parallel, the terminal voltage will be equalized and a momentary flow of wattless current I_w will be set up through the local series connections between the two armatures. The magnitude of this synchronizing current will be proportional to the initial terminal potential difference $\frac{1}{2}(E_{t2} - E_{t1}) = e_w$. As a further consequence of equalizing the terminal voltages, the output of the leading generator will be enlarged in proportion to the rise of its terminal voltage, while the load on the lagging generator will be correspondingly reduced, so that at the instant of paralleling, the relative loads carried are directly proportional to the values of sin $(\alpha_0 + \alpha_s)$ and sin $(\alpha_0 - \alpha_s)$, respectively.

119 By virtue of the governor action this additional load put upon the leading generator will immediately cause its engine speed to drop, while the other engine carrying the lesser generator load will have its speed accelerated. After

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making the necessary governor adjustments, each of the generators will eventually assume an equal share of the load.

120 The division of the load will to some extent be disturbed by the armature oscillations which the irregular crank effort is capable of setting up. If the armature oscillations should at any time become sufficiently large to again shift the armatures out of their mean lead position by a maximum angular displacement of $+\alpha_s$ and $-\alpha_s$, respectively, then at the instant of reaching these limiting shift positions it is evident that the same wattless current I_w will again be made to flow in quadrature with E_{ll} and its magnitude will be proportional to the vector length $e_w = A_1A_0' = A_0'A_2$.

121 This relation is brought out more clearly in Fig. 10, in which the dotted current vectors are drawn in their true quadrature position with respect to the

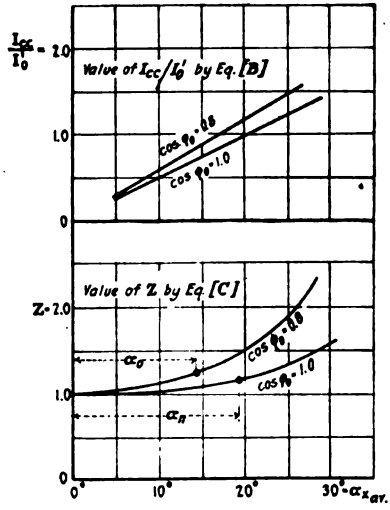

FIG. 11 RELATION OF CROSS-CURRENT FLOW TO SHIFT ANGLE α_s

pressure vectors. In this figure the average armature displacement $\pm \alpha_{s_{av}}$ is used to fix the position of the shifted vectors, as this determines the current flow as read by ammeter measurements.

122 After the alternators have been connected in parallel, the current flowing out of the leading armature may be measured by the vector difference of $A_0'C_1$ (*i.e.*, I_1' of Fig. 9) and the wattless current I_w, which form a resultant equal to I_1. The corresponding vector difference for the lagging armature is I_2. The flow of wattless current shifts the two current vectors I_1 and I_2 into the phase relation ϕ_1 and ϕ_2, respectively, as indicated in the diagram.

123 The total current delivered to the external circuit by the two alternators is represented by the combined vector length $A_0'C_0$, which is equal to $2\,I_0'$, having the average or external phase ϕ_0 with respect to the terminal pressure E_{ll}.

124 Fig. 10 further shows that the resultant cross-current flow in the local series connection between the two armatures is to be measured by the vector difference of the currents I_w and $(I_1' - I_0')$, which is equal to I_{cc}, as indicated in

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the case of the leading generator by the small dotted triangle $B_1C_1B_0'$. In other words, the difference in the phase relation of the current vectors I_1 and I_2 will set up a resultant cross-current between the two paralleled generators equal to the vector length I_{cc}, which is in phase with the excitation vector E_{z0} and has a power factor equal to cos α_0 with respect to the terminal pressure E_{t0}. Accordingly, the cross-current power is $I_{cc}E_{t0}'$ cos α_0, which work measured in terms of diagram area becomes equal to E_{t0} (E_{z0} sin $\alpha_{z_{cc}}$ cos α_0). As indicated to the right of Fig. 10, the cross-current work is therefore equal to the total diagram area OB_1A_0' for the leading generator, minus the average output of either generator as measured by the mean area $A_0 = OB_0'A_0'$.

125 The average generator output corresponding to the area A_0 is equal to $I_0'E_{t0}'$ cos ϕ_0, which in turn is proportional to the mean turning force P_c acting normal to the engine crankpin. Accordingly, the pull P_{cc} exerted by the cross-current pull for any angular armature-displacement shift ϕ becomes equal to

$$\frac{P_{cc}}{P_c} = \frac{E_{t0}'\, I_{cc} \cos \alpha_0}{E_{t0}'\, I_0' \cos \phi_0} = \frac{\sin \alpha_{z_{cc}}}{\sin \alpha_0} \cos \alpha_0 \quad \text{[A]}$$

126 The balanced cross-current pull P_{cc} acts in the manner of the spring forces in the analogous flexible coupling and tends to pull the armatures into closer synchronism.

127 A numerical value for the cross-current flow per phase may be found by transposing Eq. [A], thus:

$$I_{cc} = \left(\frac{\cos \phi_0}{E_{z0} \sin \alpha_0}\right) I_0' \cdot E_{z0} \sin \alpha_{z_{cc}} = \frac{I_0' E_{z0}}{e_0} \cdot \sin \alpha_{z_{cc}} = I_s' \sin \alpha_{z_{cc}} \quad \text{[B]}$$

where I_s' = generator short-circuit current per phase at an excitation E_{z0}.

128 The above equation represents the minimum expected cross-current flow as based upon the assumption of equal excitation and identical constructive characteristics for both of the paralleled generators. The relation between I_{cc} and I_0 is plotted in the upper curve of Fig. 11, assuming the generator characteristics to be such that $I_s = 3\, I_0$.

129 Referring again to the diagram, Fig. 10, the mean shift positions of the leading and the lagging armatures are respectively indicated by the vectors OB_1 and OB_2, while OB_0 represents the zero or reference position from which to measure the mean angular displacement shift $\pm\alpha_{z_{cc}}$. The ammeter reading in any one of armature circuits may, therefore, be expected to pulsate between the limits I_1 and I_2, which are equal respectively to the vector sum and difference of I_0' and I_{cc}. The current vector diagram further shows that the corresponding ammeter reading in the external or line circuit will vary between the limits $2\, I_0'$ and $2\, I_0$, while the common line voltage will swing between E_{t0}' and E_{t0}, their relation being

$$\cos \alpha_x = \frac{I_0'}{I_1} = \frac{E_{t0}'}{E_{t0}}$$

130 It is further evident that the arithmetical sum of the two armature currents which the generators send to their respective switchboard panels, i.e., I_1 and I_2, will always be greater than their vector sum $I_0 + I_0'$, the total current delivered to the external circuit. The ratio of these readings as taken from the diagram, Fig. 10, becomes equal to

$$Z = \frac{I_1 + I_2}{I_0 + I_0'} = \frac{e_1 + e_2}{e_0 + e_0'} \quad \text{[C]}$$

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131 As stated, the vectors in Fig. 10 are drawn for the leading and lagging armature in their respective average shift positions $\pm\alpha_{z_{av}}$ as deduced from the equations previously given. This mean angular shift fixes the cross-current flow P_{cc}, or vice versa, the factor Z of Eq. [C] may be directly determined by current measurement and the cross-current estimated from it. The factor Z as found graphically from the given vector diagrams is plotted upon an $\alpha_{z_{av}}$ base in the lower curve of Fig. 11.

132 Finally, it may be pointed out that should the sum of the armature, displacement angles $\alpha_z + \alpha_0$ at any time exceed $\pi/2$ electrical radians, or one-half pole pitch, the paralleled generators would then be thrown out of step. Before reaching this limiting shift position the cross-current flow would assume prohibitive proportions. As indicated by the dotted-and-dashed vectors OB_1' and OB_2' in Fig. 10, the maximum angular displacement shift α_z may exceed α_0 without throwing the generators out of step, but at such periods the lagging armature would have to be dragged along instead of serving as a current producer.

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No. 1617

A VOLUME REGULATOR FOR BLAST-FURNACE ENGINES

By L. C. Loewenstein, West Lynn, Mass.
Member of the Society

Blast-furnace operation has attained a high degree of refinement in the proportioning of the various materials composing the charge — the ore, the fuel and the flux. The weight of oxygen — introduced as atmospheric air — per charge has, however, until recently been subject to much uncertainty due primarily to the difficulty of measuring with any degree of accuracy the volume of air delivered. The adjustment of the air supply to the furnace was, therefore, usually made only when the operator found evidence that the furnace was badly overblown or underblown, a process which resulted in a more-or-less variable product and certainly in a reduction in the possible maximum output of the furnace.

With the advent of the centrifugal compressor giving a perfectly steady air blast, the metering of the air supply became more practical and, therefore, more usual. With perfectly definite and uniform charging a definite and uniform weight of air per minute is desirable. Constant-volume governors have been designed on two principles, one by metering the air by means of a venturi meter and the other by using an impact float. The venturi-meter governing has been improved by using a multiple venturi meter in which large pressure drop can be obtained in the throat without a corresponding loss in power. This difference in pressure is used on a mercury pot whose motion up and down is translated to the governing mechanism of the driver of the air compressor. The proper setting of this meter is accomplished by changing the tension of the spring until a scale calibrated in cubic feet of air per minute shows that the desired quantity of air is obtained.

In the impact float method the air is taken through a conical opening in which is suspended a float, this float moving a horizontal beam about a pivot. The horizontal beam actuates the governing mechanism of the driver of the air compressor. On this horizontal beam is a sliding weight which can be set at calibrated marks representing cubic feet of free air per minute. With the weight set in a definite position a certain definite quantity of air is obtained.

In both of these methods, however, the readings on the calibrated scale are only correct when the initial air conditions are standard, that is, are similar in barometer, temperature and humidity to which the scale has been calibrated. Any change in either the temperature of the inlet air or in the atmospheric barometer or in the humidity of the air, changes the weight of the air metered, and, therefore, its oxygen content. As the blast furnace requires an exact weight of oxygen, the above method

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of holding constant volume is liable, in extreme cases, to have an error of from 15 to 20 per cent.

A volume corrector is herewith presented which when used in connection with the air-metering device will correct for any changes in either temperature, barometer and humidity, so that the air supplied to a blast furnace will, at all times, under any atmospheric conditions, deliver a perfectly definite and predetermined weight of oxygen to the blast furnace. This volume corrector is so designed that it requires only one setting for each correction, that is, one setting for any initial temperature, one setting for any existing barometer and one setting for humidity as usually obtained by the difference of readings on a wet- and dry-bulb thermometer.

THE proper regulation of the quantity of air supplied to a blast furnace deserves careful study, the results aimed at being a more uniform quality of product and a greater output per furnace. The latter feature, while always very valuable, assumes espetial importance during these war times. But, before considering the problem of regulation, it might be well to state in very simple terms the primary function of a blast furnace.

FUNCTIONS OF A BLAST FURNACE

2 The blast furnace is primarily an apparatus for producing pig iron; but incidentally it may also be regarded as a huge gas producer. The materials fed to it are the iron ore, the fuel (coke), and the fluxes (limestone), which are charged at the top of the furnace or throat; and the air blast, which is blown in near the bottom of the furnace at the tuyeres. The materials discharged from the furnace are pig iron and slag, which are tapped from the bottom or crucible of the furnace, and the gases and dust, which pass out of the top of the furnace. The iron ore in a blast furnace is deoxidized or reduced, for which purpose the furnace is charged with sufficient carbonaceous fuel to do two things: to abstract all the oxygen from the reducible metallic oxides and to furnish enough heat at high enough temperature to melt down to superheated liquids the pig iron and slag, — combinations of irreducible metallic oxides, — that are formed. The fuel must supply the reducing energy and the melting-down or smelting requirements; the first by action upon the metallic oxides at a red to a white heat and abstracting their oxygen; the second by being burned at the foot of the furnace by the hot-air blast, and there generating the heat and higher temperatures necessary for the smelting down of the materials already reduced.

3 In a secondary way the blast furnace may also be regarded as a huge gas producer, run by hot forced blast, in which the incombustible portions of the contents are melted down (with a little un-

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burnt carbon) to liquid metal and slag, and are run out beneath, while the gaseous products pass upwards through 50 to 100 ft. of burden, and escape above. The escaping gases are primarily of the composition of producer gas, with some of its carbonous oxide changed to CO_2 by the oxygen abstracted from the burden; with some CO_2 added from the decomposition of the carbonates of the charge: and with the usual increment of moisture from the charge and volatile matter (if any) from the distillation of the fuel. Hence, the blast furnace is a huge gas producer, giving a rather inferior quality of combustible gas in large quantities, while reducing to metal and slag the burden of iron ore and flux (limestone) which is put in with the fuel. In fact, the unoxidized and combustible ingredients of the escaping gas represent a large part, often the largest part, of the total calorific power of the fuel.

AIR REQUIREMENTS IN BLAST FURNACES

4 From the above it can be readily seen that if the charging of a furnace is uniform it is quite essential to have the amount of air supplied to the furnace also uniform in quantity. The air pressure required for forcing the air through the furnace varies with the condition of the burden or charge. If the particles of ore, fuel, and limestone are large, that is, the spaces between these particles ample, there is a freer passage for the air than if the particles of ore, fuel, and limestone are small and closely packed. Under certain conditions the furnace may require a pressure of, say, 10 to 15 lb. to force a certain quantity of air through it, while under other conditions, when the material in the furnace is tightly packed, a much higher pressure, sometimes as high as 25 to 30 lb., is required to force through the same amount of air.

AIR COMPRESSORS FOR BLAST FURNACES

5 It is therefore absolutely necessary that the air compressor be capable of adapting itself automatically to supply a predetermined *weight* of air, corresponding to the charge in the furnace, regardless of the resistance encountered up to a certain prescribed maximum. Usually, the limiting air pressure is 30 lb., as this is the maximum pressure the stack itself will withstand with safety.

6 The expression *weight of air* is used advisedly, because the blast furnace requires a definite weight of oxygen to combine with the carbon in the coke charged to the furnace. In general practice we refer to this definite weight of air (or oxygen) as a "constant volume

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of air," but this volume must have reference to specific conditions of temperature, barometer and humidity, because any variation of these conditions changes the weight of oxygen contained in a given volume. The standard conditions most commonly referred to are dry air at 60 deg. fahr. temperature and 30 in. barometer. Air under these specified conditions contains, of course, a perfectly definite weight of oxygen per cubic foot.

RECIPROCATING ENGINES AND BLOWERS

7 Up to the advent of the centrifugal compressor, reciprocating compressors were chiefly used for blast-furnace work. The governor of the compressor driver was set to maintain a speed corresponding to the desired quantity of air, the general idea being that each stroke of the compressor represented a practically constant quantity of atmospheric air regardless of the discharge pressure. A little reflection will show, however, that, at the end of the discharge stroke, the clearance space is full of high-pressure air, which must expand to atmospheric pressure on the return stroke before fresh air from the outside can be admitted. Now, assuming equal temperatures, the volume of a given weight of air is inversely proportional to the absolute pressure. So that with a clearance space of, say, 7 per cent and a discharge pressure of, say, 10 lb. per sq. in. gage or 24.7 lb. per sq. in. absolute, the air in the clearance space must expand $\frac{24.7}{14.7} \times 7$ or 11.8 per cent of the cylinder contents before fresh air can be admitted into the cylinder on the return stroke of the piston; while with a discharge pressure of 30 lb. gage or 44.7 lb. absolute, the air in the clearance space must expand to $\frac{44.7}{14.7} \times 7$ or 21.3 per cent of the cylinder contents before atmospheric air can be admitted. The useful travel of the piston is therefore reduced from 88.2 per cent of the cylinder contents to only 78.7 per cent. Then higher pressures mean higher final temperatures; and as the incoming air is heated by the clearance-space air and by the cylinder walls, a smaller weight of atmospheric air is admitted for a given travel of piston. Finally, higher pressures result in greater leakage by the piston rings from the high-pressure to the low-pressure end, thus further lowering the quantity of air admitted. These various influences greatly reduce the volumetric efficiency of a reciprocating compressor when operating at a constant r.p.m. against increased pressures.

8 The r.p.m. of the reciprocating compressor being thus but a

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poor guide as to the weight of air supplied, it was left to the judgment of the blast-furnace operator as to whether or not the furnace was receiving the proper amount of air. If in his opinion the furnace was receiving too little air, that is, if it was underblown due to the charge in the furnace offering more resistance to air flow than previously, he would call for a higher speed of the reciprocating compressor. Speeding up the driver would then furnish a somewhat greater quantity of air at the higher pressure. If, however, the blast furnace was overblown, the reciprocating compressor was slowed down, and the quantity of air furnished was reduced. This method of operating, however, necessitated a decided change of condition in the furnace before the furnace operator knew that the air supply to the furnace was not correct, and in many cases the furnace got into a very poor condition before the operator changed the air supply and improved conditions.

9 With the gradual introduction of greater refinements in determining the quantities and the chemical composition of the ore, fuel and flux entering each charge in the blast furnace, the uncertainty in the quantity of air supplied began to stand out more and more as the weakest link in the chain. There was not only the need for a reliable method for measuring the quantity of air, but engineers were asking for apparatus which, while metering the air, would also automatically maintain constant any desired quantity, regardless of the furnace conditions. Before entering, however, into a discussion of the commercial methods for regulating the supply of air to a blast furnace, it may be advisable to review briefly the underlying theory and the more usual methods of measuring air in general.

THEORY AND FORMULÆ FOR FLOW OF GASES

10 If a gas, such as air, is allowed to flow from a region of higher pressure to one of lower pressure, the velocity attained by the gas is a definite function of the difference of pressures of the two regions. Expressed mathematically,

$$V^2 = 2g \int_{P_2}^{P_1} \frac{dP}{\gamma} \quad \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

where

V = spouting velocity in ft. per sec.
g = acceleration of gravity, 32.16 ft. per sec. per sec.
P_1 = initial (high region) pressure in lb. per sq. ft.
P_2 = final (low region) pressure in lb. per sq. ft.
γ = local density of gas in lb. per cu. ft.

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For an incompressible fluid, in which γ is independent of the pressure, the above equation becomes

$$V^2 = 2g\frac{P_1 - P_2}{\gamma} \quad \text{.....[1a]}$$

11 If the flow takes place adiabatically, that is, so that the heat changes taking place in the gas during the flow are due wholly to the pressure changes in the gas and to no other cause whatever, then

$$\frac{P_1}{\gamma_1{}^K} = \frac{P_2}{\gamma_2{}^K} \quad \text{.....[1b]}$$

where K is the ratio of the specific heat at constant pressure to the specific heat at constant volume for the particular gas. Equation [1] thus becomes:

$$V^2 = 2g\frac{K}{K-1}\frac{P_1}{\gamma_1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}\right] \quad \text{.....[2]}$$

12 If this spouting velocity takes place through an orifice of A sq. ft. having a velocity coefficient f (determined experimentally), the discharge W in lb. per sec. is:

$$W = fA_2\gamma_2\sqrt{2g\frac{K}{K-1}\frac{P_1}{\gamma_1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}\right]}$$

or

$$W = fA_2\sqrt{2g\frac{K}{K-1}P_1\gamma_1\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{K}} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}}\right]}$$

or

$$W = fA_2\sqrt{2g\gamma_1\frac{K}{K-1}}\sqrt{P_1\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{K}} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}}\right]} \quad \text{.....[3]}$$

13 For Eq. [3] two cases must be distinguished: First, when $\frac{P_2}{P_1}$ is above a certain critical value (about 0.53 for air and 0.58 for steam), in which case the flow depends both on P_1 and on P_2 as per Eq. [3]; and secondly, when $\frac{P_2}{P_1}$ is below the critical value, in which case the flow is independent of the actual value of P_2 but is determined by a pressure P_c which automatically establishes itself in the

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throat (real or virtual) of the discharging orifice or nozzle. P_c is given by the relation

$$\frac{P_c}{P_1} = \left(\frac{2}{K-1}\right)^{\frac{K}{K-1}} \quad \text{.....[3a]}$$

which, substituted in Eq. [3] gives:

$$W = fA_c\gamma_c\sqrt{2g\frac{K}{K+1}\frac{P_1}{\gamma_1}}$$

or

$$W = fA_c\sqrt{2g\frac{K}{K+1}P_c\gamma_1} \quad \text{.....[3b]}$$

where A_c is the area of the throat or least section.

14 For practical computation work, the weight of the gas is expressed not in pounds but in cubic feet per second, at certain standard conditions (usually 14.70 lb. per sq. in. absolute and 60 deg. fahr.), and the exponential quantities

$$\left(\frac{P_2}{P_1}\right)^{\frac{2}{K}} \quad \text{and} \quad \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}}$$

are each expanded in a series of terms. Eqs. [3] and [3b] are then written respectively as

$$Q = fa\frac{3.97}{\sqrt{T_1\gamma_0}}\sqrt{p_2(p_1-p_2) - \left(\frac{1.5}{K}-1\right)\left(p_1-p_2\right)^2} \quad \text{.....[4]}$$

and

$$Q = fap_1\frac{3.97}{\sqrt{T_1\gamma_0}}\sqrt{\frac{K}{K+1}\left(\frac{2}{K+1}\right)^{\frac{2}{K-1}}} \quad \text{.....[4a]}$$

where

Q = cu. ft. of standard gas per sec.
a = area of orifice in sq. in.
T_1 = initial (high-pressure region) temperature in. deg. fahr., abs.
p_1 = initial pressure in lb. per sq. in., abs.
p_2 = final pressure in lb. per sq. in., abs.
γ_0 = density at 14.70 lb. per sq. in. and 60 deg. fahr. in lb. per cu. ft.

15 For air [4] and [4a] become respectively

$$Q = fa\frac{14.52}{\sqrt{T_1}}\sqrt{p_2(p_1-p_2) - 0.0665(p_1-p_2)^2} \quad \text{.....[5]}$$

and

$$Q = fap_1\frac{6.98}{\sqrt{T_1}} \quad \text{.....[5a]}$$

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16 The velocity of the air can at any point in the path be easily reconverted into a pressure which is equal to the difference of pressure producing this velocity and is therefore proportional to the γV^2 at the particular point. This pressure is usually measured by a column of water or of mercury; or, if it is too large, it is measured directly in lb. per sq. in. The use of a pressure gage, however, is not recommended, as such gages are usually inaccurate in spite of frequent calibrations. It is much preferable to use a dead-weight gage arrangement as shown in Figs. 1*a* and 1*b*. The pipe or tubing brought from

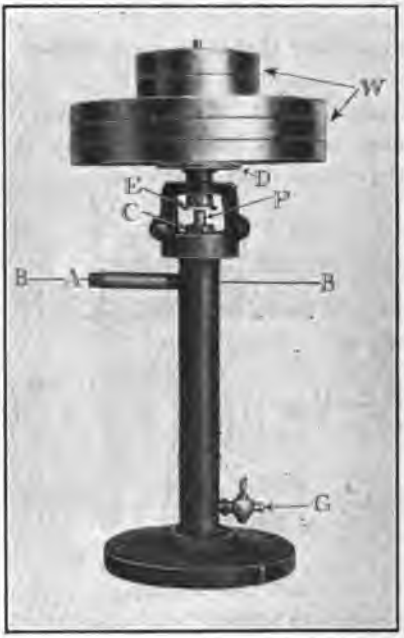

FIG. 1*a* USUAL TYPE OF DEAD-WEIGHT PRESSURE GAGE

the point where pressure is to be measured (in an air or steam main, for instance) is connected to pipe *A* which leads into a chamber filled with oil up to the level *B-B'*. A piston *P* (usually having an area of $\frac{1}{8}$ sq. in.) fits snugly into a tube *C* and carries a disk *D*. Weights *W* are placed on *D* until the air or steam pressure is correctly balanced, which is shown by the disk floating easily. To insure against sticking, the disk is constantly rotated, and to insure against having the piston lifted entirely out of the tube, collar *E* is provided, which prevents lifting the disk higher than the yoke above the collar. The photo-

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graph of a similar dead-weight tester shows the older method of design. In the old design the pressure was admitted by a pipe shown extending horizontally from a vertical tube. The latter is filled with oil. The weights, disk, piston, and tube are similar in design as shown in Fig. 1*b*. The difficulty with the old design as shown in the photograph is that water of condensation quickly fills the oil reservoir, drives the oil out by leakage and finally leaves nothing but water in place of oil. In the new design shown in Fig. 1*b*, if there is

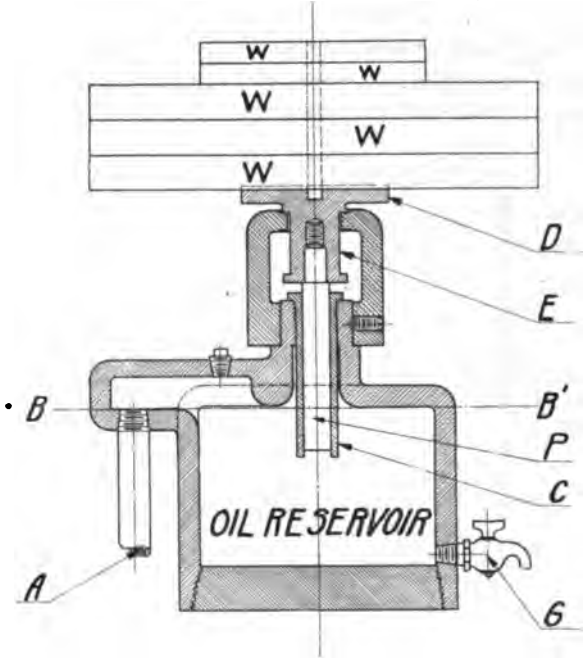

FIG. 1*b* IMPROVED TYPE OF DEAD-WEIGHT PRESSURE GAGE

any water introduced to pipe *A*, it will settle into the bottom of the reservoir and can be drained out through the cock *G*. The reason the inlet pipe *A* in Fig. 1*b* and the horizontal inlet pipe shown in the photograph are carried up to the level as indicated is to insure that the pressure measured is considered from the level *B-B'* which is the level of the oil under pressure. This is important when measuring small amounts of pressure, as a difference in the height of the location of the dead-weight gage adds or subtracts such distance from the small pressure to be recorded.

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COMMERCIAL METHODS FOR MEASURING AIR

17 The commercial methods for measuring air most commonly employed are: (1) The Receiver Method, (2) The Orifice Method, (3) The Pitot Tube, (4) The Venturi Meter, and (5) The Impact Float Method. Of these the first two methods waste the air they pass, and are therefore suitable only for temporary testing purposes. The other methods allow the air to pass to destination, and may therefore be left continuously in the system.

RECEIVER METHOD

18 In the Receiver Method, the compressed air is passed into a closed system consisting of a tank and piping of known dimensions and full originally of air of atmospheric pressure and temperature,

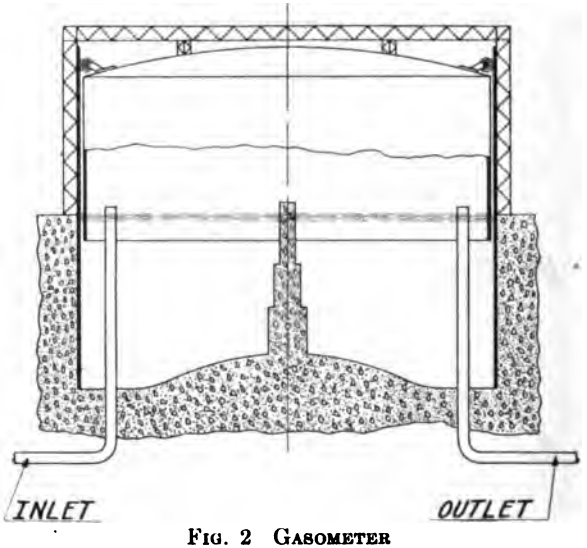

FIG. 2 GASOMETER
Can be used as a receiver for metering air

which conditions are taken as standard. After the compressed air has been flowing into the system for a sufficiently long period, say, half an hour or an hour, the pressure and the temperature are again observed. If the cubic contents of the system is V cu. ft. and the standard or original absolute pressure and absolute temperature are P_0 and T_0 respectively, and the final conditions are P and T, the final volume in the system referred to standard condition is $V\frac{PT_0}{P_0T}$ cu. ft., and the inflow is $V\left(\frac{PT_0}{P_0T}-1\right)$ cu. ft. of standard air.

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19 A tank as shown in Fig. 2 (similar to a large gas container) may also be used. The entering air raises the bell against gravity and atmospheric pressure, so that the pressure of the air in the tank is perfectly definite; and the volume can be read off directly from the rise of the bell after sufficient time has been allowed for the air to come down to atmospheric temperature.

20 The chief advantage of this method is that the measurement of the air is definite and is entirely independent of any coefficients. Its principal use is in connection with the calibration of orifices and the determination of the volumetric efficiency of very small reciprocating compressors. Evidently the measurement of the flow from a blast-furnace compressor would require a receiver system of entirely unwieldly and impractical dimensions.

ORIFICE METHOD

21 In the Orifice Method the compressed air is allowed to discharge into the atmosphere through an orifice of known area and known velocity coefficient. The temperature T_1 is measured by

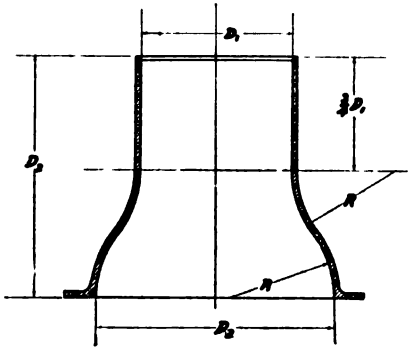

FIG. 3 STANDARD ORIFICE

Proper proportions are given, and for orifice diameters of one-half to one-third of the diameter of the air-discharge piping, coefficient of flow is very nearly 0.99

means of a bare thermometer inserted through the wall of pipe immediately preceding the orifice without well or casing of any kind. The type of orifice ordinarily used is the kind for which Equation [5] applies; that is, an orifice which is correct for a final pressure above the critical pressure. Such an orifice is theoretically wholly convergent, and it may stop with the smallest section attained. Practically, however, it is desirable to attach a parallel section of appreci-

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able length to the end of the orifice, as shown in Fig. 3, to guide the air in parallel straight lines and thereby insure that the jet of air has the same diameter as the orifice end; in other words, that there is no *vena contracta* effect at the exit end of the orifice.

22 While the pressures p_1 and p_2 may, of course, be observed independently, it is preferable to observe the pressure drop $p_1 - p_2$ by means of an impact tube connected to an ordinary U-tube as shown in Fig. 4*a*. The impact tube is held in the center of the jet at a distance from the plane of the orifice equal to about $\frac{1}{8}$ of the orifice diameter. The difference of level in the U-tube is a correct

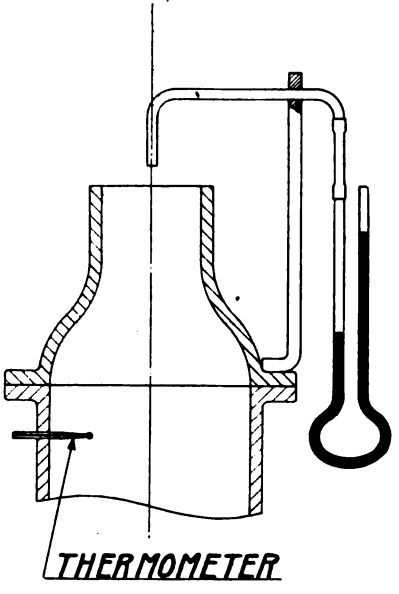

FIG. 4*a* IMPACT TUBE MOUNTED ON STANDARD ORIFICE

measure of the velocity head of the jet, since the static pressure of the jet is atmospheric. In other words, the full discharge pressure, if so desired, may be converted into velocity energy at the orifice end and then reconverted by the impact tube into the original pressure. The readings of the impact tube can, therefore, be made as large as desired; and even when measuring air flow from a compressor delivering a very low pressure, good readings on a water U-tube can be obtained. Fig. 4*b* shows the orifice in Fig. 4*a* mounted on a length of air-discharge piping for test purposes. During a compressor test, power readings are generally taken for a large number of loads and

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quick and accurate readings on the impact U-tube by the use of the ordinary yardstick or rule are difficult, especially if the mercury or water column is oscillating somewhat.

23 For such cases the use of the U-tube illustrated in Figs. 5

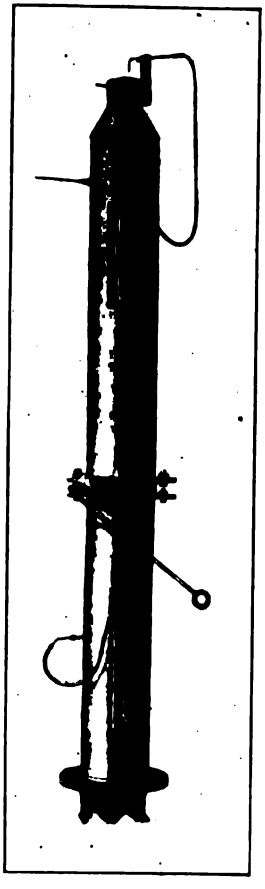

FIG. 4b ORIFICE WITH IMPACT TUBE[1]

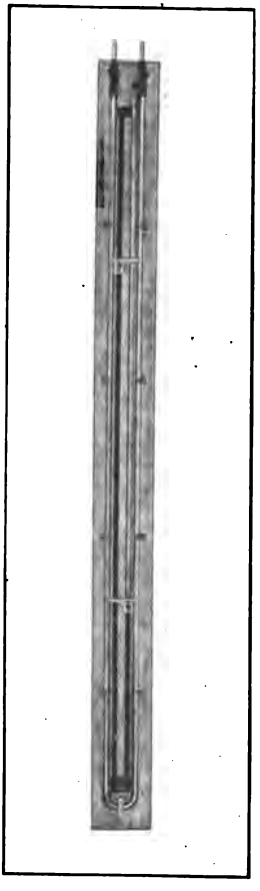

FIG. 5 IMPROVED TYPE OF U-TUBE[2]

[1] Shown mounted on air-discharge pipe as used in test.

[2] The steel scale with proper pointers can be set at the fluid levels and distance between pointers read directly on steel scale. Especially convenient for measuring slightly oscillating fluid levels.

and 6 is strongly recommended. On the four-grooved board the U-tube is supported in the two outer grooves and two properly shaped metal pointers slide easily in the inner grooves. To one of these

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pointers a graduated steel scale is attached, the zero on the scale starting at the pointer, so that this pointer is used for the lower level on the U-tube. The steel scale is kept taut by being counterweighted over a roller at the top of the board. The other pointer passing across the steel scale is set for the upper level, and thereby reads on the scale the difference in levels. By the use of this apparatus the observer is enabled to set the pointers at their respective levels at any time previous to the stated time for taking readings and he can keep

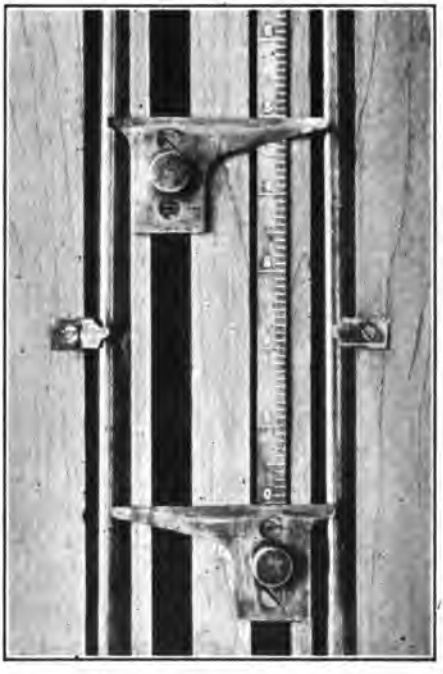

FIG. 6 ENLARGED VIEW OF SCALE AND POINTERS FOR U-TUBE IN FIG. 5

these pointers set continuously at the lower and upper levels on the U-tube. As soon as any change of these levels occurs the observer can instantly make a corresponding change of the pointers. This leaves him free at the instant of taking the readings to observe simply if the pointers are indicating correctly the lower and upper levels of the U-tube, or their mean levels if the liquid in the U-tube is oscillating. He can then read the length between the two pointers at his leisure. This is a great deal more convenient than having to set

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at the instant the reading must be taken, one end of the measuring stick at the lower level of the U-tube, and quickly catch the reading of the upper level on this scale.

24 An observer manipulating a long measuring stick close up to the U-tube cannot possibly observe both the lower and upper levels quickly and take a reliable numerical reading; whereas with the device described above he can stand away from the instrument and take an instantaneous check by observing if both pointers stand correctly at the proper levels. Instead of a continuous glass U-tube, which is rather expensive and easily liable to break in transportation and by jars, it is preferable to make the lower connecting piece of iron pipe to which the straight glass lengths are joined by rubber tubes.

25 The Orifice Method can be used for measuring the very smallest as well as the very largest volumes of air occurring in practice. The velocity coefficient f for well-shaped orifices such as shown in Fig. 3 when of 4 in. throat diameter (D_1) and over may safely be taken as 0.99.

26 Next to the Receiver Method, the Orifice Method is the most certain and the most reliable method for measuring air, and it is therefore generally recommended as the standard for the calibration of other air-measuring methods. A uniform rate of flow, however, is presupposed, as a pulsating flow, such as comes from reciprocating or positive-pressure compressors, cannot be measured reliably by any method which depends on a γV^2 observation unless the discharge piping is of an extreme length, sufficient to dampen out all pulsations.

PITOT-TUBE METHOD

27 The Pitot Tube shown in Fig. 7 is used for measuring the velocity head in a transmission pipe. Essentially it consists of two tubes, one of which, A, passes straight into the service pipe to measure the static pressure, while the other tube, B, is made to point upstream to measure the sum of the static pressure plus the velocity head. The combination of these two tubes gives the velocity head alone as shown on the middle U-tube C in Fig. 7. Equation [5] applies, f being practically unity, a being the pipe area, p_2 the static pressure, and $p_1 - p_2$ the differential reading. Since, to keep down friction losses, the velocity in the transmission pipe is usually very low, various artifices, such as an inclined tube, have to be resorted to, to get a reliable reading of $p_1 - p_2$. Also, the measurement of static pressure, unless special precautions are taken, is subject to serious error.

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A good deal of work has been done in devising an instrument to read correctly and not be subject to the common errors so often occasioned by improper installation of the pitot tubes. This has been reported from time to time before The American Society of Mechanical Engineers.

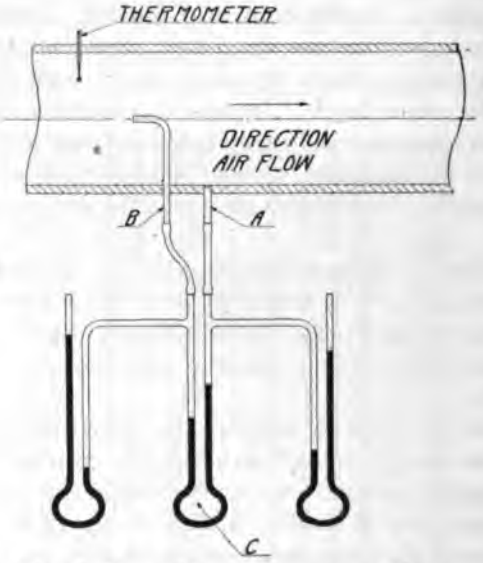

FIG. 7 PITOT TUBE, ELEMENTARY FORM

28 Fig. 8 illustrates a commercial flow meter on the pitot-tube principle embodying the latest ideas on the subject. For instance, the reading $p_1 - p_2$ is magnified as shown diagrammatically in Fig. 9

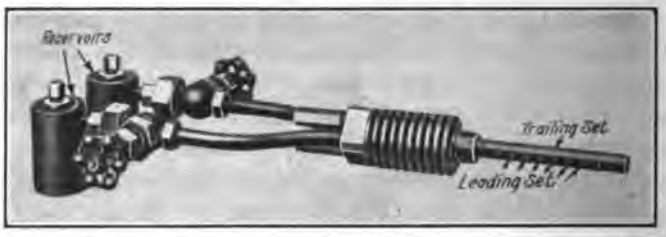

FIG. 8 NOZZLE PLUG OF AIR-FLOW METER WITH LEADING AND TRAILING OPENINGS

by having the static leg of the U-tube point downstream, so that the drag of the gas or fluid over the trailing opening lowers the pressure in that leg and thereby increases the differential reading in the U-tube

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corresponding to the given velocity. Also the impact pressure and the static pressure are obtained more accurately by means of a nozzle plug as shown in Fig. 8 inserted in the service pipe. The single leading and the single trailing opening shown in Fig. 9 are here replaced by a leading set of openings extending approximately across the diameter of the pipe, while the trailing set of openings is located

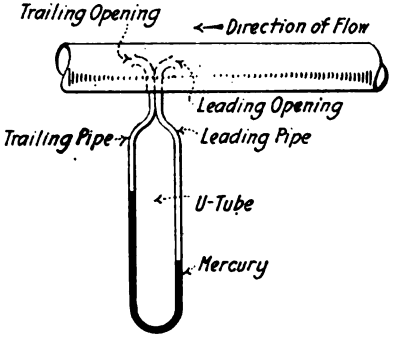

FIG. 9 DIAGRAMMATIC ILLUSTRATION OF NOZZLE PLUG AS USED IN FLOW METER OF FIG. 8

midway between the ends of the tube at the center of the pipe diameter, and faces in the direction of the flow. The introduction of the nozzle plug in the pipe line causes no appreciable drop in the pressure even at very high rates of flow.

VENTURI METHOD

29 The Venturi Meter shown diagrammatically in Fig. 10 consists essentially of a direct and a reversed nozzle placed throat to throat, making a common throat. In general, two U-tubes B and D or the equivalent, are necessary, one to give the static pressure B in the throat and the other to give the pressure drop D from the main pipe, or high-pressure region, to the throat. It will be noticed that the impact tube A points upstream, so as to include whatever velocity head may exist in the main pipe. After the air passes the throat, the pressure rises again to nearly, but not quite, its original value. This may be demonstrated by the use of impact tube C, pointing upstream, in the pipe beyond the throat. U-tube F communicating with both impact tubes A and C will give directly the pressure loss caused by the insertion of the venturi meter into the system.

30 The direct nozzle should be short and well rounded, while the reversed nozzle should be well tapered with a half angle of about

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4 deg. The inside of the meter must be smoothly finished, and particular care must be taken at the entrance of the U-tube into the throat of the meter to avoid all burrs and roughness. Also the impact tube in the main pipe should be small to avoid any eddies and disturbances due to the introduction of the impact tube.

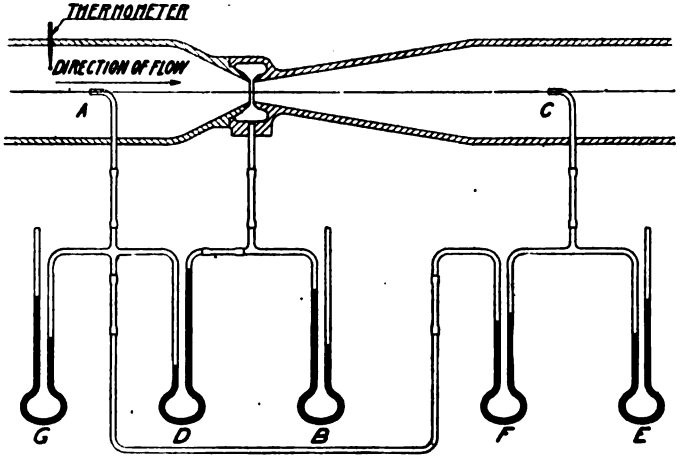

FIG. 10 VENTURI METER

Readings on U-tubes *B* and *D* and of the barometer are necessary

31 The quantity of air may be computed by Eq. [5]. As the U-tubes are generally used with mercury, it is convenient to write Eq. [5] in the following form:

$$Q = 423\,fa\,\frac{1}{\sqrt{T_1}}\sqrt{P_2\,(P_1 - P_2) - 0.0665\,(P_1 - P_2)^2} \quad \ldots\ldots [6]$$

where

Q = cu. ft. of standard air (14.70 barom. and 60 deg. fahr.) per min.
T_1 = absolute temperature in main pipe in deg. fahr.
f = velocity coefficient of throat, usually between 0.95 and 0.99
a = area of throat in square inches
P_1 = absolute initial (high) pressure in inches Hg
P_2 = absolute pressure in throat in inches Hg
$P_1 - P_2$ = pressure drop.

32 In designing a venturi meter for a particular case, the area a is so chosen that the value of $P_1 - P_2$ for the quantity of air most commonly used should be large enough to be read conveniently

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and with reasonable accuracy and yet not so large as to cause an excessive pressure drop and power loss in the meter.

33 It is preferable to measure the air before it is compressed, so that P_1 and T_1 are the atmospheric pressure and absolute atmospheric temperature, respectively. A single U-tube like U-tube B in Fig. 10 is then sufficient. The actual pressure P_1 must be obtained from the existing barometer and then P_2 can be computed from the reading $P_1 - P_2$ on the U-tube.

34 The U-tube can also be calibrated in cubic feet of air per minute instead of indicating only inches of mercury pressure. When so calibrated it can only refer to some standard or average condition of air, and any change in temperature, barometer or humidity will affect the correct reading on such a calibrated scale.

IMPACT FLOAT METHOD

35 The Impact Float Method described previously in a paper by Mr. R. H. Rice before this Society and illustrated in Fig. 11 consists in allowing the air to be metered to impinge on a float F, usually in the form of a disk, suspended vertically in a cone. The air enters the small end of the cone and its velocity is steadily reduced as it passes up toward the larger end of the cone. The force tending to lift the float, and whatever is attached to it, against gravity consists partly of the direct impact of a part of the air against the float, and partly of the pressure drop caused by the passage of the air through the annulus between the float and the cone in a sort of *vena contracta*. As the float rises in the cone, this force is reduced by the lowered velocity of the air, so that the position of the float in the cone is a function of the quantity of air passing through the cone.

36 It is desirable, however, for reasons which will appear later in connection with air regulation, to confine the position of the float within narrow limits, regardless of the quantity of air. This is accomplished as shown in Fig. 11 by connecting the float to a horizontal lever or beam B, the force on the float being balanced by a sliding weight W, which can be moved to any part of the beam. The beam is so graduated that the position of the sliding weight on it gives directly the volume of the air entering the cone.

37 The impact on the float or the momentum of the air is evidently mV, where m is the mass of air impinging on the float per second and V is its velocity. Since for a constant cross-section, m is proportional to γV, where γ is density of the air, the impact on

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the float is proportional to γV^2 or to $\frac{m^2}{\gamma}$. Similarly, the pressure drop through the annulus around the float is $\gamma \frac{V^2}{2g}$, where V is now the velocity in the annulus, and is therefore also proportional to $\frac{m^2}{\gamma}$.

38. When the air flows through the annulus between the float and cone a *vena contracta* obtains whose area varies with each volume of air flowing. On account of this, formulæ for the float force or

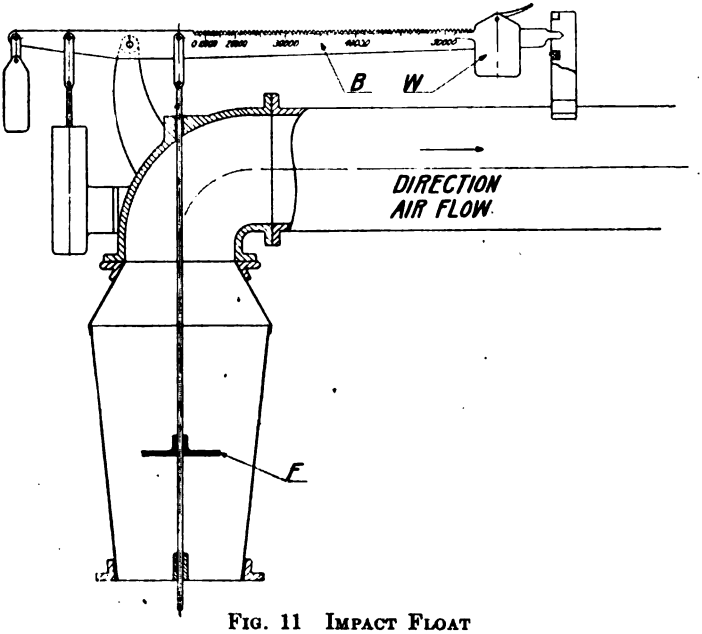

FIG. 11 IMPACT FLOAT
Air meter

reaction based on purely mathematical deductions require modification based on experimental results. The slope of the cone and the ratio of float diameter to cone diameter and also the average velocity of the air through the cone influence the value of this float force. For long cones having a slope of about one inch in five inches and with floats having areas between 50 per cent and 95 per cent of the annulus area and using average velocities through the cone under 100 ft. per sec., the following formula found experimentally will hold:

$$F = 9 \times 10^{-4} Q^2 \gamma \sqrt{\frac{A}{a^3}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [7]$$

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in which

F = total force of float in lb.
Q = cu. ft. of air per min.
γ = density of the air in lb. per cu. ft.
A = float area in sq. ft.
a = annulus area in sq. ft.

39 The upward moment of the force F about the fulcrum of the beam (Fig. 11) is counterbalanced partly by the downward moment of the weight of the float and partly by the moment of the sliding weight, which is downward but may be upward for small volumes of air. In any case, however, the system may be reduced to one having a weightless float and beam, so that the upward moment of the float force F is balanced by the downward moment of the sliding weight W. Since both the weight W and the lever arm of F are fixed, the lever arm of W must be always proportional to the force F, or to $\frac{M^2}{\gamma}$, in which M is Q referred to standard conditions of barometer, temperature and humidity, and therefore represents a definite weight of air.

40 In other words, the beam must have a quadratic scale; that is, the longitudinal distance of the sliding weight from the zero on the beam is four times as great for 20,000 cu. ft. and nine times as great for 30,000 cu. ft. as it is for 10,000 cu. ft. The graduations on the beam are made correct for the average atmospheric conditions of the air at the place where the instrument is to be used.

41 In metering the air all that is necessary after the beam is calibrated is to move the sliding weight W along the beam until the beam is level, exactly as in the case of the beam on a pair of beam scales. The pointer on the weight W then indicates the amount of air flowing.

CONSTANT-VOLUME GOVERNING

42 Of the above-mentioned methods of measuring air in general, only the last two, the Venturi Meter and the Impact Float, are commercially used for regulating the supply of air to blast furnaces. With the advent of the centrifugal compressor a blowing apparatus became available which could be very nicely regulated in respect to holding any constant volume of air supply to the furnace. The centrifugal compressor delivers an absolutely steady stream of air without any pulsations whatever and the pressure delivered by such a unit varies closely with the square of its speed. Hence, any volume

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regulation of air need only influence the speed of the driver of the centrifugal compressor. Up to a very short time ago all volume regulation for centrifugal compressors was based upon a calibrated scale for some standard condition of air, usually assumed as dry air at the average temperature and barometer existing at the location of the set. We again emphasize here the fact that constant-volume governing is referred to, whereas the object desired is to introduce a constant *weight* of oxygen into the furnace.

43 The governing of a centrifugal compressor, in order to hold constant volume, requires the use, first, of a meter for measuring the volume of air flow. The necessary qualifications of such a meter, taking into consideration the large quantities of air used in blast-furnace operation, are: (1) It must not waste any of the air it meters; (2) the power consumed in the metering and governing processes must be small, which makes it necessary that the friction losses of air flow through the meter be small; (3) the governor must be sensitive so that a small change in the quantity of air supplied will be sufficient to actuate the governor.

THE MULTIPLE VENTURI METER

44 An ordinary venturi meter in which the entire quantity of air flowing must be drawn through a sufficiently small throat to give a suitable drop of pressure would involve considerable power loss. To reduce this power loss a multiple venturi has been devised, consisting of a number of concentric venturis. Referring to Fig. 12, which shows a multiple venturi, a very small part of the total air flow passes through the small or inner venturi. At the throat of this small venturi the largest pressure drop is obtained. A larger quantity of air flows around the inner venturi and through the second venturi, but the bulk of the air flow is around the second and through the third or outer venturi.

45 Consider a flow of 45,000 cu. ft. of standard air per minute through the triple venturi shown in Fig. 12, the air flowing from right to left as indicated. The air at inlet to the venturi is assumed to be at practically atmospheric pressure and temperature. By the use of Equation [6] and by assuming a probable velocity coefficient $f = 0.95$ for the inner venturi and $f = 0.85$ for the two outer venturis, we can show that the following conditions obtain. Through the inner venturi 175.8 cu. ft. of standard air flows. The pressure at the throat is 22.65 in. Hg, representing a drop of pressure of 7.28 in. Hg. About 1777 cu. ft. of standard air per minute flows through

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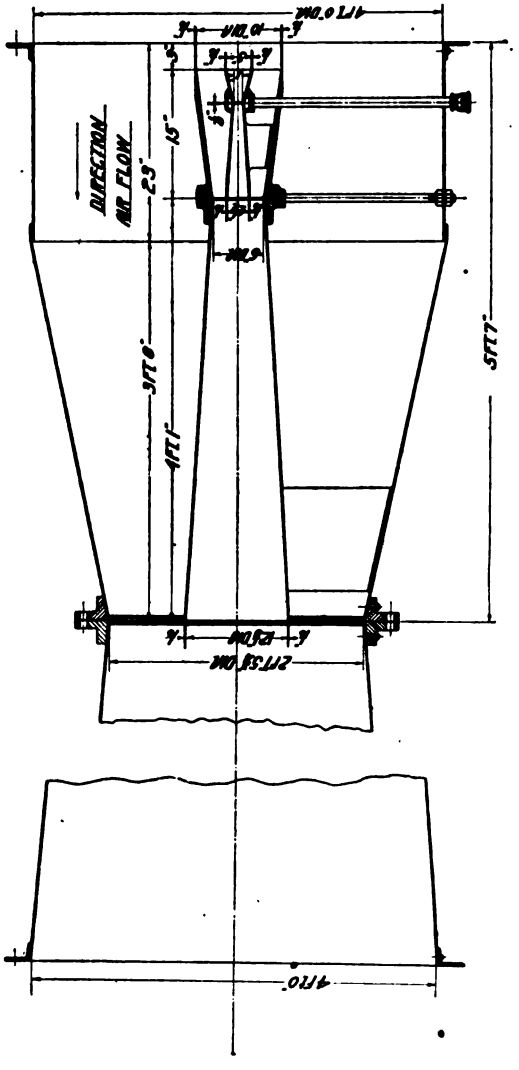

FIG. 12 TRIPLE VENTURI METER

Used for securing a reasonable drop of pressure without excessive power loss

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the middle venturi. The drop of pressure from atmosphere (29.93 in. Hg) to the throat of this venturi is 0.73 in. Hg. All the remaining air (43,047 cu. ft.) passes through the outer or third venturi, and the drop of pressure from atmosphere to the throat of this venturi is 0.69 in. Hg.

46 The loss of power in metering the air through this triple venturi, when passing 45,000 cu. ft. of standard air per minute, can be determined from the loss of pressure between that existing at the entrance to each venturi and the pressure existing at the exit or discharge end of each venturi, taking into account the volume of standard air passing through each. This gives a loss of power of 0.18 hp. for the smaller or inner venturi, 1.06 hp. for the middle venturi and 31.38 hp. for the outer or largest venturi, making a total power loss through the entire triple venturi of 32.62 hp.

47 The largest drop of pressure in this triple venturi meter occurs in the throat of the inner or smallest venturi. With a flow of 45,000 cu. ft. of standard air per minute, the calculated drop is 7.28 in. Hg (3.57 lb. per sq. in.) pressure. With air entering the meter from atmosphere the throat pressure will be negative (suction). With varying flow of air through the venturi the suction at the throat of the inner venturi will also vary; and this varying suction can be used for governing the driver of a centrifugal compressor so as to hold a definite "*constant volume*" of air flow per minute.

THE VENTURI METER CONSTANT-VOLUME GOVERNOR

48 Fig. 13 shows in a somewhat diagrammatical manner a means for accomplishing this. The pipe leading from the throat of the inner venturi meter is connected to part *A* representing a mercury-sealed pressure bell, or mercury pot. Suction pressure at the venturi throat is established in the space *B* between the stationary part of the pot and the upper and movable bell. Variations of pressure in *B* cause this bell to move up or down. The suction pressure is sealed from atmosphere by a column of mercury surrounding the long sheet-steel skirt or extension of the bell. There is sufficient clearance space between this sheet-steel skirt and the inner and outer shell surrounding it to prevent any frictional contact. The movement of the bell in the mercury pot is transmitted through the links *C*, *D*, and *E* to the steam-valve control to the turbine, thereby opening and closing the number of valves admitting steam to the turbine. An adjustable spring *F* can be set so as to counterbalance the pull of the bell for any desired volume of air. Handwheels *G* are used for

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setting the spring tension, as can be readily understood from the figure.. Dashpot *H* dampens out the oscillations of this gear.

49 The method of setting for regulation is as follows: Having determined exactly the number of cubic feet of standard air desired per minute, the operator turns the handwheel *G* and observes the height of the registering mercury column also attached to the pipe leading from the throat of the inner venturi. This mercury column is not only inscribed in inches of mercury, but is also calibrated in cubic

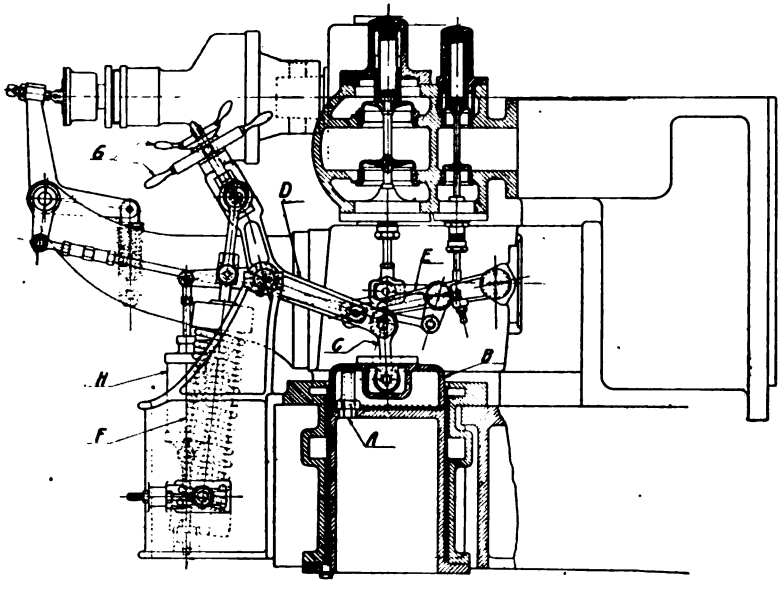

FIG. 13 CONSTANT-VOLUME GOVERNOR FOR VENTURI METER

Uses a mercury pot subjected to the pressure of the throat of the venturi meter shown in Fig. 12 and with adjustments so that it can hold any desired volume as indicated on a calibrated mercury tube shown in Fig. 14

feet of air per minute, as shown in Fig. 14.[1] When the mercury column registers the desired number of cubic feet of standard air per minute, handwheel *G* is locked. Any change in air flow through the venturi will change the suction in the pipe leading from the throat of the inner venturi to the mercury pot shown in Fig. 13 and also to the gage in Fig. 14. A change of suction on the mercury pot, however, influences the governing mechanism so as to increase the steam ad-

[1] For Figs. 12, 13 and 14 the author is indebted to the Southwark Foundry and Machine Company.

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mission to the turbine when the suction decreases, or decrease the steam admission to the turbine when the suction increases. By this means constant-volume governing is obtained. Increasing the steam admission to the turbine speeds up the unit, thereby increasing the discharge pressure of the compressor, and vice versa. Equilibrium must be established between the spring tension set by handwheel

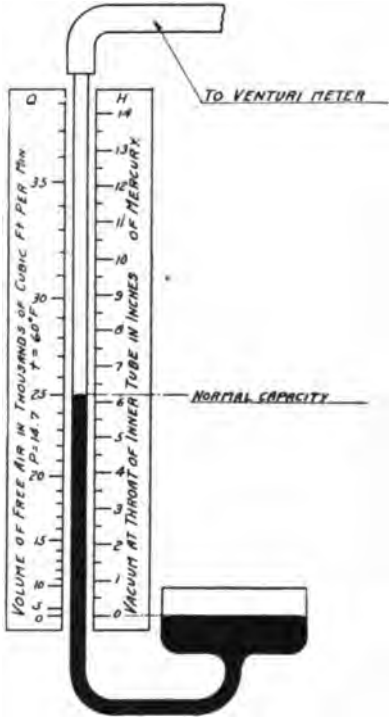

FIG. 14 U-TUBE AND QUANTITY SCALE FOR VENTURI METER

Used with a venturi meter as shown in Fig. 12 and with a constant-volume governor as shown in Fig. 13

G and the pressure in the confined space in the mercury pot before the governing mechanism comes to rest.

50 The calibration of mercury column indicating number of cubic feet of air per minute refers to standard air, that is, air of the average temperature and barometer and humidity for which the unit has been calibrated. Fig. 14 shows a calibrated scale for a normal capacity of 25,000 cu. ft. of air per min., whereas Fig. 12 shows a multiple venturi of a much greater normal capacity, probably 40,000 cu. ft. per min.

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THE IMPACT FLOAT CONSTANT-VOLUME GOVERNOR

51 The second method for regulating turbo-compressors for blast-furnace work involves the use of the impact float which was originally conceived as part of the means for constant-volume governing. Fig. 11 shows the impact float suspended in a conical pipe and attached to a beam calibrated in cubic feet of air per minute. If this beam were attached by linkages to the governing mechanism of the driver of a centrifugal compressor it could be made to take care of its governing.

52 Fig. 15 shows such a constant-volume governor. Float *F* is suspended by a vertical rod from beam *B*. The float is made so it can be heated with a small amount of compressed air introduced through the hollow suspension rod *S* so as to prevent moisture from condensing and freezing upon the float in winter. The beam is fulcrumed at *A* and is balanced by counterweight *C* and movable sliding weight *W*. Dashpot *D* prevents too rapid movements or oscillations. Handwheel *H* on one end of the beam moves the sliding weight *W* longitudinally along the beam by means of a threaded shaft and nut. The sliding weight can thus be set at any definite position indicating the desired volume of air per minute. Any movement of the beam is transmitted through linkages *M*, *N*, *O* and *T* to a controlling pilot valve *V* which will admit steam or oil under pressure to either one or the other side of a piston *P*. This piston is connected directly to a nest of controlling valves which admit steam to separate groups of turbine nozzles. The turbine governor *G* is used as a speed-limiting device, so arranged that when the turbine reaches a speed corresponding to that at which the compressor would deliver the maximum permissible pressure (for blast-furnace work usually 30 lb. per sq. in. gage), it moves linkages *L*, *K*, and *N* and thereby influences the governing pilot valve from opening more valves for steam admission. In other words, at this speed it takes the control of the turbine out of the hands of the constant-volume governor.

53 The important feature of this method of constant-volume governing is the very small pressure drop involved by the air passing through the conical pipe of the meter. The area of the float is so large that a very low velocity of air and an extremely small pressure difference on the two sides of the float is sufficient to afford all the force necessary to move the entire governing mechanism. This fact also makes the governor sensitive to the smallest variation in the quantity of air passing through the compressor.

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54 The force exerted upon the impact float when used as a constant-volume governor can be determined from Equation [7] previously given.

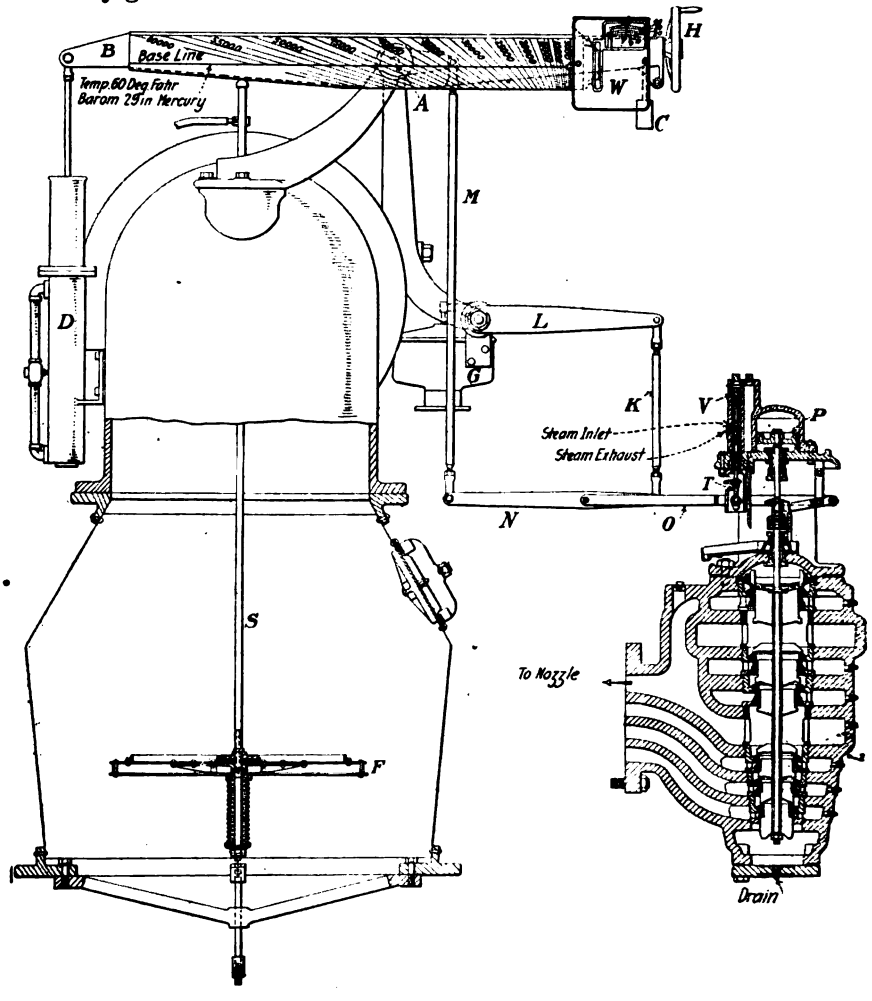

FIG. 15 VOLUME CORRECTOR
Shown mounted on the beam of a constant-volume governor

55 It has been found advisable to make the area of such a float equal to

$$A = 700 \frac{Q_1^3}{Q} \frac{1}{\sqrt{p^3 \gamma}} \quad \text{.....[8]}$$

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in which

A = area of float in sq. ft.
Q = correct quantity of cu. ft. of standard air per minute for a definite position of sliding weight
$Q_1 = Q + q$
q = smallest change of volume in cu. ft. of air per min. desired to produce an effect governing
γ = density of air in lb. per cu. ft.
p = mean effective pressure in lb. per sq. in. for which the compressor has been designed.

56 It will be noticed that the smaller the value of q, the more sensitive will be the governing and the smaller will be the force available for governing purposes. If q is taken reasonably large the governing forces become greater but the constant-volume governor will be less sensitive. In other words, q is a measure of the per cent of the regulation desired.

57 When the float is in proper position for the compressor to deliver its normal rating of air against the normal pressure, the annulus area between the float and the cone may be found from the following equation:

$$a = 0.0017\, Q \sqrt{\frac{\gamma}{P_m}} \qquad [9]$$

in which

a = annulus area in sq. ft.
Q = the normal rating of the compressor in cu.ft. of air per min.
P_m = the mean effective pressure corresponding to the normal pressure rating in lb. per sq. in.
γ = density of air in lb. per cu. ft.

58 It is advisable to make the inlet pipe diameter for supplying atmospheric air to the constant-volume governor and hence to the compressor of such diameter as to limit the velocity of air to approximately 30 ft. per sec. The constant-volume-governor cone should extend into an inlet box which would admit air with uniform distribution into the cone. It is therefore advisable to have the inlet box as large as possible.

59 Table 1 gives an idea of the float forces and float areas employed in practice, the float force having been measured experimentally in each case.

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TABLE 1 FLOAT AREAS AND FORCES USED IN IMPACT FLOAT METHOD

Normal rating of unit, cu. ft. of standard air per min.	Quantity of air delivered, cu. ft. per min.	Float area, sq. ft.	Float force, lb.
50,000	45,000	7.43	168
40,000	40,000 35,000	6.87	167 128
30,000	30,000 25,000	4.90	171 118
20,000	22,500 20,000 18,300	3.14	112 89 75

INACCURACIES OF CONSTANT-VOLUME GOVERNORS

60 Both the venturi meter and the impact float methods of constant-volume governing applied to centrifugal compressors have resulted in improving the regulation of blast furnaces. Unfortunately, this means of regulating cannot be applied to any other type of air-compressing machinery because all other known types of compressors do not produce an absolutely steady flow of air. The advent of constant-volume governing has eliminated the only remaining guesswork heretofore employed in regulating the air supply to a blast furnace. With careful analysis of the iron ore and coke charged to the furnace and a careful weighing of them as they are charged, the amount of oxygen necessary for combustion of the coke and reduction of the iron ore is accurately and easily determined. It is then only necessary in the venturi method to adjust the governing mechanism so that the indicating mercury column shows the desired quantity of atmospheric air per minute; or, in the impact float method, merely to set the sliding weight on the governing beam to the indicated quantity of atmospheric air desired. In the latter case the weight can be set immediately and the governor will automatically establish the proper air flow, whereas, in the former case adjustment must be made slowly until the desired air flow is obtained. In both cases, however, if the atmospheric conditions of the inlet air change from the so-called standard or average conditions for which the governors were calibrated, the actual quantity of air delivered, or more correctly, the actual *weight* of oxygen sent to the blast furnace, will vary. This variation may be considerable.

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61 For instance, if the standard air conditions are taken as dry air at 60 deg. fahr. and 29 in. Hg and the governor is calibrated for these conditions, it is possible to conceive a summer condition of 100 deg. fahr. with a barometer of 26 in. and fully saturated air (as on a rainy and stormy day). There is 14 per cent less oxygen per cubic foot of air under these conditions than under standard conditions. In winter, atmospheric air may be at 0 deg. fahr., the air perfectly dry and a barometer of 30 in. Hg. A cubic foot of this air will contain 8 per cent more oxygen than the standard air. It is, therefore, perfectly possible to supply from 8 per cent too much oxygen to 14 per cent too little oxygen to the blast furnace, if regulation is dependent on constant-volume-governor settings of standard or average conditions of atmospheric air.

THE VOLUME CORRECTOR

62 The main object of this paper is to describe a new instrument named a volume corrector which can be applied to the sliding weight and calibrated scale of an impact-float constant-volume governor for correcting this governor when handling air of any temperature, barometer or humidity. An instrument similar in principle and somewhat similar in construction can also be applied to the indicating mercury column of the venturi meter so as to obtain proper volume correction.

63 The volume corrector applied to the impact-float constant-volume governor is shown in Fig. 15. The scale beam *B*, instead of having vertical calibration lines for standard conditions of air, has sloping constant-volume lines engraved upon it. The volume corrector proper is mounted on the front of the sliding weight *W*. Fig. 16 is a photographic view of a part of this scale beam with volume corrector mounted on the sliding weight; and Fig. 17 is the same with the hinged door of the volume corrector open, as is the case when the instrument is to be set.

64 Fig. 18 shows a little more clearly the arrangement of this instrument. There are three milled heads, *A*, *B*, and *C*, provided for adjusting pointers indicating barometer, temperature and humidity. All that is required of the operator is to set these pointers correctly. After obtaining the actual barometer reading from a standard barometer, and the actual temperature of the incoming air, and observing the existing humidity — which is usually done by noting the temperature difference between a wet- and dry-bulb thermometer, pointer *a* is set at the proper barometric reading, pointer *b* at the

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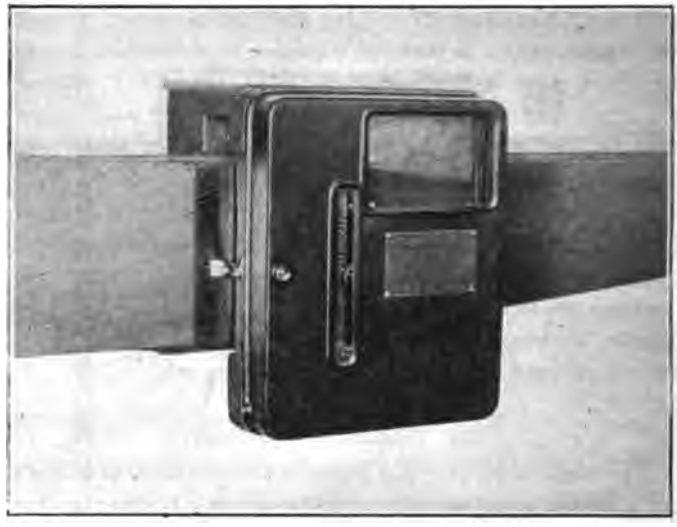

FIG. 16 PHOTOGRAPHIC VIEW OF THE VOLUME CORRECTOR
Front door of casing closed

FIG. 17 PHOTOGRAPHIC VIEW OF VOLUME CORRECTOR
Front door of casing opened

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proper temperature reading, and pointer *c* moved so as to intersect the curve corresponding to the observed temperature difference between the wet- and dry-bulb thermometers.

65 The movement of each of these pointers influences the final position of the main pointer *P*. This main pointer moves in a vertical direction with respect to the scale on the beam. After the volume corrector is properly set, the sliding weight to which the volume corrector is permanently attached is moved horizontally along the

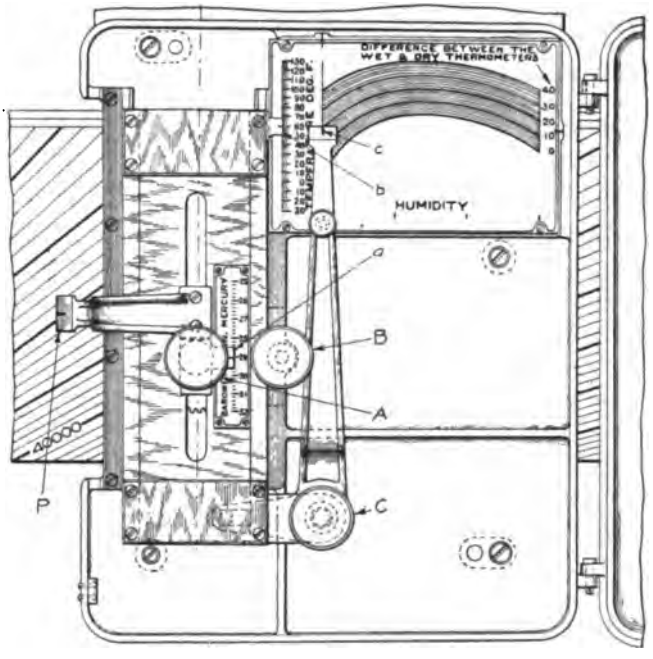

FIG. 18 VIEW OF VOLUME CORRECTOR SHOWING DETAILS

beam until the main pointer *P* intersects the sloping line on the graduated scale designating the proper volume of standard air required. When so set the sliding weight is in the proper position. This permits corrections to be made for variation in temperature, barometer and humidity so that a constant *weight* of oxygen is supplied no matter what the conditions of the atmospheric air. Having determined that the blast furnace requires a definite volume of standard air (dry air at 60 deg. fahr. and 29 in. Hg), the governor with corrected setting of the sliding weight will deliver the proper amount of

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actual air which would contain the same *weight* of oxygen as would be contained in the required quantity of standard air.

66 The amount of oxygen in dry air varies directly as the density of the air. The density of air is directly proportional to the barometric pressure and inversely proportional to the absolute temperature. Expressed symbolically, $\gamma \propto \frac{B}{T}$. As the float force is proportional to $\frac{M^2}{\gamma}$, a change in density γ with the governor set to maintain a constant weight M of air per second will cause the governor to change the speed of the compressor until a new weight M_1 is delivered, such that the new value of $\frac{M_1^2}{\gamma_1}$ is the same as the original value of $\frac{M^2}{\gamma}$. Expressed symbolically, for a given setting of the sliding weight, $M^2 \propto \gamma$, or $M \propto \sqrt{\gamma} \propto \sqrt{\frac{B}{T}}$. For moist air the barometer no longer represents the pressure of the air itself, for part of the barometric pressure is due to the vapor pressure in the air. This vapor pressure must therefore be subtracted from the observed barometric pressure in order to get the net air pressure to be used in computing the air density and hence the weight of oxygen per cu. ft. of air. For saturated air (a relative humidity of 100 per cent) the vapor pressure can be read directly from steam tables for the observed atmospheric temperature. If the air is not quite saturated, the relative humidity, or the percentage of the possible maximum of moisture in the air, can be determined in a number of ways; usually, from a dry- and wet-bulb thermometer arrangement. The vapor pressure for a given temperature is proportional to the relative humidity, and this must then be subtracted from the observed barometric pressure in computing the air density.

67 The graduated scale on the beam of the constant-volume governor was designed by taking a horizontal base line such as was shown in Figs. 15, 16 and 17, and shown schematically in Fig. 19 as AA', and placing thereon the proper calibration for standard air (dry, 60 deg. fahr., 29 in. Hg). The zero on this line gives the position of the sliding weight when the constant-volume governor beam is in equilibrium and no air is flowing. The point B (Fig. 19) represents the position of the sliding weight for 10,000 cu. ft. flow; and point C its position for 20,000 cu. ft. flow, etc. The distance AC is made equal to four times AB. Similarly the distance AD, where D represents the 30,000 cu. ft. point, is made equal to nine

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times AB. With respect to temperature, the graduations on AA' hold good so long as the prevailing atmospheric temperature is 520 deg. fahr. absolute. When the prevailing temperature is other than 520 deg. fahr. absolute, the relations of the distances AB, AC, AD to each other remain unchanged; but they must all be multiplied or foreshortened by the same ratio. This is accomplished in the following manner:

68 Referring to Fig. 19, let the line OAB' be perpendicular to the base line AA'; and let OA represent to some scale 520 deg. fahr. absolute, and OB' represent 2080 deg. fahr. absolute to the same scale, so that $OB' = 4\,OA$. Draw $B'C'$ parallel to AA' and CC' parallel

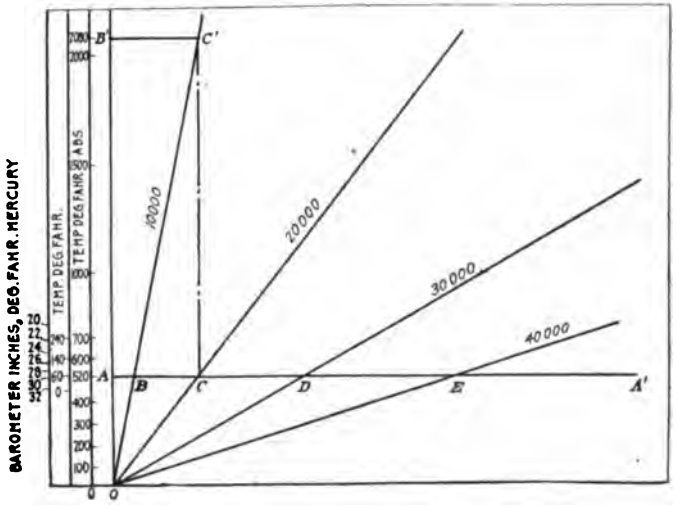

FIG. 19 DIAGRAM ILLUSTRATING CONSTRUCTION OF SCALES ON VOLUME CORRECTOR

to OB'. Also prolong the straight line OB until it intersects the line $B'C'$ in the point P (not shown). The triangles OAB and $OB'P$ being similar, $B'P : AB :: OB' : OA$; or $B'P = 4\ AB$. But $B'C' = AC = 4\ AB$. Therefore $B'P = B'C'$; or P coincides with C'. In other words, the intersection C' of the line CC' with $B'C'$ is a point on the straight line OB.

69 Now in actual operation when the governor is set to deliver 20,000 cu. ft. of standard air per minute for a temperature of 520 deg. fahr. and should the actual temperature be four times as high, or 2080 deg. fahr. absolute, the governor will, as explained before, with the same setting of the sliding weight, regulate for only 10,000 cu.

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ft. of standard air per minute, because the density of the air at 2080 deg. fahr. absolute is one-fourth of that at 520 deg. fahr. absolute. The pointer of the sliding weight must under those conditions then read 10,000 cu. ft. without the sliding weight itself being disturbed in any way. In the volume corrector this would be accomplished by pushing up the final pointer along a uniform temperature scale until it reads 2080 deg. fahr. absolute, because the pointer traveling upward would then, as proved above, just intersect the 10,000 cu. ft. line *OBC'*. It will be noticed that all the sloping lines representing definite volumes of air per minute meet at *O*. This would represent the point of absolute zero if the same temperature scale was carried down on the prolongation of the line *AB*. From the above it can be seen that if the volume corrector be made to carry a temperature scale with the same distances as employed in the engraving of the scale on the beam, and the main pointer *P* of the volume corrector be made to move vertically up and down the proper distance to this scale, the sliding weight can be set for any observed temperature of atmospheric air so as to deliver the proper volume of air containing the same weight of oxygen as is contained in the previously calculated necessary volume of air of standard conditions.

70 Further consideration will show that as far as the density or the square of the volume is concerned, doubling the absolute temperature is equivalent to halving the barometer. In other words, any barometric change can be expressed by an equivalent temperature change. For instance, if 29 in. Hg is taken as the standard barometer and 60 deg. fahr. (520 deg. absolute) as the standard temperature, a change to 28 in. barometer, the temperature remaining at 60 deg. fahr., is equivalent to a change to a temperature of $\frac{29 \times 520}{28}$ or 538.6 deg. fahr. absolute (78.6 deg. fahr.) with the barometer remaining at 29 in. Hg. The distance on the barometer scale from 29 in. to 28 in. must therefore equal the distance from 60 deg. fahr. to 78.6 deg. fahr. on the thermometer scale, whereas the correction necessary from 29 in. Hg to 25 in. Hg barometer is equivalent to a change to a temperature of $\frac{29 \times 520}{25}$ or 603.2 deg. fahr. absolute (143.2 deg. fahr.) with the barometer remaining at 29 in. Hg. The distance on the barometer scale from 29 in. to 25 in. must therefore equal the distance from 60 deg. fahr. to 143.2 deg. fahr.

71 The barometric scale constructed on the above principle for the volume corrector is evidently a reverse and reciprocal (that is,

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non-uniform) scale. For constructional reasons, and chiefly to take care of humidity corrections explained later, it is desirable to have this scale uniform without affecting in any way the accuracy of the instrument. This is accomplished in the following manner.

72 Referring to Fig. 20, which gives a view of the volume corrector shown in Fig. 18 but with some of the front cover plate removed, *A*, *B* and *C* are the pins to which the milled heads *A*, *B* and *C* of Fig. 18 are attached. The main pointer in Fig. 18 is moved up and down in a vertical slot by means of pin *p* in Fig. 20. When the

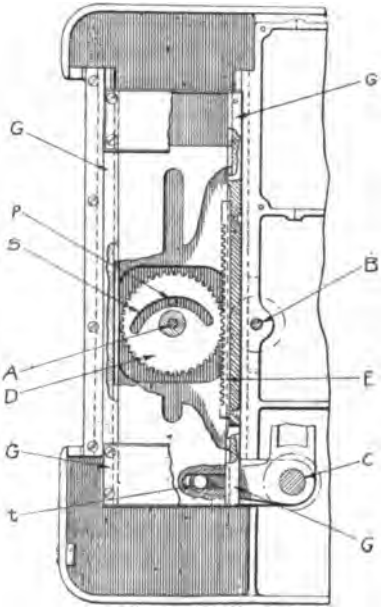

FIG. 20 SECTIONAL VIEW OF VOLUME CORRECTOR

operator moves milled head *A* so that pointer *a* indicates the barometer reading, gearwheel *D* (Fig. 20) rotates about pin *A* because it is meshed into a rack *E* which remains stationary. Motion is given to pin *p* (which is held in a vertical slot) by the slot *S* in gearwheel *D*. This slot is in the form of a cam and so designed that pin *p*, and therefore the main pointer *P*, moves the proper distance vertically. The main pointer will move a less distance vertically when barometer pointer moves from 32 in. to 31 in. than it will when moving from 31 in. to 30 in., and less from 31 in. to 30 in. than it will from 30 in. to 29 in. Therefore, although the barometer

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scale over which pointer A moves has uniform divisions, the actual vertical distance through which the main pointer P moves is non-uniform and follows a reciprocal scale.

73 The setting of temperature is accomplished through milled head B which is attached to a plate movable vertically between gibs GG and which carries with it the rack E, gearwheel D, and pin p with main pointer P. Moving B up and down does not revolve gearwheel D at all (that is, does not disturb the barometer setting), but simply moves main pointer P over a temperature scale shown in Fig. 18. Pointer b is set opposite the proper temperature reading.

74 The corrections for humidity in the volume corrector are based upon the following considerations: The barometric-pressure reading as usually observed is equal to the sum of the air pressure plus the vapor pressure. If the air is saturated, that is, if it contains all the water vapor it is capable of holding without precipitation at the particular temperature, the value of the vapor pressure at the given temperature can be ascertained experimentally or taken from the steam tables. If the degree of saturation or the relative humidity is, say, only 20 per cent or 50 per cent, then the vapor pressure as determined experimentally must be multiplied by 0.20 or 0.50 as the case may be.

75 The most usual method of ascertaining the relative humidity of the air is by means of a wet- and dry-bulb thermometer arrangement. In its simplest form it consists of two similar thermometers, the bulb of one of which is covered by a wet piece of sponge. If the air is fully saturated no evaporation into it can take place and the two thermometers record the same temperature. When the air is only partly saturated, the evaporation from the wet bulb lowers the thermometer reading; so that the difference in the readings of the wet and dry thermometers can be taken as a measure of the relative humidity of the air. For any combination of relative humidity and atmospheric temperature the vapor pressure is a definite quantity. This vapor pressure must be subtracted from the observed barometer reading in order to give the net or correct air pressure to be used on the barometer scale above described; since it is the density (and therefore the actual pressure) of the air alone that is of importance, and not the density of the mixture of air and water vapor.

76 It is important to note that the humidity correction in pounds per square inch or in inches of mercury is independent of the actual barometer reading, and depends only on the atmospheric temperature and on the difference between the wet- and dry-bulb

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thermometer readings (relative humidity). The humidity correction can therefore be made mechanically if the pointer P on the sliding weight is given an additional correction or movement which would be the equivalent amount of a certain subtraction of pressure on the barometric scale equal to the correction for the pressure due to vapor. It is for this reason that it is preferable to make the divisions on the barometric scale uniform, so that, for instance, a half-inch mercury correction would require the same movement no matter at what reading the barometer scale happened to be set. As will be shown later, the volume corrector accomplishes this, therefore no matter where the barometer pointer a is set, the humidity correction moves the main pointer P on the sliding weight the proper amount. It will also be noticed that the humidity is a function of the atmospheric temperature, that is, when the temperature is high the water vapor in the saturated air is higher than when the temperature is low. In the volume corrector the setting of the temperature pointer b on the temperature scale automatically sets the humidity pointer c to the correct temperature also.

77 Referring to Fig. 18, the correction for humidity is made by loosening milled head C and swinging pointer c until it intersects or indicates the proper amount of difference in reading between the wet- and dry-bulb thermometer. The movement of the long arm carrying pointer c about the center of milled head C moves pin t attached to a plate carrying gearwheel D, but does not move rack E. Moving gearwheel D vertically up or down rotates D because E is stationary and thereby moves the main pointer P similarly, as heretofore described.

ACCURATE CONSTANT-VOLUME GOVERNING

78 The volume corrector therefore is an instrument which can be set by an operator at the existing barometer, temperature and humidity of the atmospheric air and when so set will permit the setting of the sliding weight on the scale beam in a position so that the constant-volume governor will hold or deliver the correct volume of air which would contain the same weight of oxygen as would be contained in a certain predetermined and desired volume of standard air.

79 This means that the blast-furnace operator, knowing the chemical compositions of the coke and iron ore and the amounts charged to the furnace in a stated period of time, can determine the exact volume of standard air (dry, 60 deg. fahr., 29 in. Hg) which

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will contain the proper amount of oxygen necessary for combustion of the coke and reduction of the iron ore in the blast furnace. He need not perform any mathematical calculations as to how much more or how much less air must be supplied when the atmospheric conditions are not those considered standard in order to be sure the blast furnace is receiving at all times its exact and necessary weight of oxygen.

80 The volume corrector needs resetting every time the operator notices any change in the barometer, temperature or difference between the wet- and dry-bulb thermometer reading in order to be sure of securing the most efficient regulation. The air conditions, however, do not vary rapidly and the practice of inserting in an engine-room log every half hour the steam pressure, r.p.m., vacuum and other information can easily be extended to include readings of the barometer, thermometer and wet- and dry-bulb instrument. Even with the front cover of the volume corrector closed, transparent places are provided which will permit any one checking or observing these settings. The need of a volume corrector is apparent from the fact that it is possible to have a variation of weight of oxygen delivered to a furnace of 5 to 10 per cent ordinarily and in extreme cases as high as 20 per cent as a result of variations in atmospheric-air conditions, especially as between winter and summer. The gains in quality and quantity of output of a blast furnace obtained even by the former methods of constant-volume governing without volume corrections will be still further improved by the use of constant-volume governing with proper volume corrections.

DISCUSSION

C. P. CRISSEY (written). In addition to the methods mentioned in Par. 17, it is also perfectly commercial and good practice to test turbo-blowers by means of a nozzle placed at the inlet. This method makes it unnecessary to disarrange the discharge piping or waste the air.

Referring to the author's remarks on the orifice method of measurement in Par. 21, I do not know of any objection to attaching a parallel section at the end of the orifice. On the other hand, experience does not show this to be necessary when the nozzle is properly shaped. The impression should not be gained that nozzles without the straight portion are inferior in accuracy or in any other respect.

A very ingenious device to allow for changes of temperature,

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barometer and humidity is described, but it is not automatic. The question at once arises why a set of tables or charts could not be used giving equivalent settings for the sliding weights. Any mechanism is liable to errors and disarrangement, and until something automatic is developed I believe that tables and charts will be more satisfactory than the device described.

R. J. WYSOR[1] (written). The author assumes that a constant weight of air should be delivered to the furnace under all conditions, whereas, from an operating standpoint, it is frequently found advisable to change this weight for different furnace conditions, beyond that corresponding to varying atmospheric conditions. Again, the author takes no cognizance of leakage after the blast has left the blower, that is, through the cold-blast main, stoves, hot-blast main and bustle pipe, with the numerous valves, seams and joints, offering opportunity for loss of air. This loss in different plants varies from probably a minimum of 5 per cent to a possible maximum of 25 per cent. And at each furnace it is a widely variant quantity due to changes in pressure and temperature of the blast, atmospheric conditions, state of repair of the system, etc. In other words, no matter how accurate the governing device may be, there is still considerable difficulty in delivering a fixed weight of oxygen to the furnace per unit time.

LINN HELANDER said that the clearance space of 7 per cent used by the author was rather high, and that 3 per cent was more usual; also that the variation in air pressure of from 10 lb. to 30 lb. seemed large for a blowing engine for which operating conditions have been established.

Again, as to the author's correction of clearance for determining volumetric efficiency, it is necessary to subtract the clearance volume from the corrected volume, which would be 7 per cent from the 11.8 per cent mentioned in Par. 7, making the corrected loss in efficiency 4.8 per cent. This must be done as the volumetric efficiency is the ratio of the piston displacement after atmospheric pressure is reached to the total piston displacement, and the difference between these two displacements does not include the clearance volume.

THE AUTHOR. In reply to Mr. Crissey, I would say that a nozzle without a straight portion can be used, but in that case there is no

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way of telling whether the jet as it leaves the nozzle covers the entire exit area.

In regard to using tables or charts for setting the sliding weights, I would say that there are three variables and an infinite number of combinations. The barometer can be set for each 0.1 in. of variation. Similarly there are an infinite number of variations of temperature and humidity, and any one who has attempted to get up a set of tables or a set of curves would realize how difficult it is and how voluminous it would be, and secondly, how much easier it would be to use the instrument by the three settings, and automatically get the proper reading, than to go over a set of tables and probably make a mistake. Also, the superintendent in walking through a blast-furnace plant can easily check up the three settings made by the operators and see that the barometer, temperature and humidity settings are correctly made. He cannot do that as readily if he has a set of tables to check.

In reply to Mr. Helander I would say that the statement made in the paper in reference to volumetric displacement is correct, because the clearance space between the cylinder head and the piston is not the entire clearance space. It includes all the clearance spaces down to the valves, and it is known that the volumetric efficiencies of blowing engines are seldom above 85 per cent in practice. The statement that a blowing engine can go from 10 lb. pressure to 30 lb. pressure deals with extremes that do not ordinarily occur, but distinct cases are known where a blowing engine normally operating at 12 to 15 lb. went all the way up to 30 lb. when the furnace tightened up.

In reply to Mr. Wysor, we contend that the old method of changing the air supply to a blast furnace to allow for different furnace conditions is exactly what a volume governor should correct. This is why a constant-volume governor increases the furnace output. It keeps the furnace condition uniform. If the quality of ore or coke changes, then the governor setting is changed accordingly. No governor can take care of air leaks in the piping, and good furnace blowing requires airtight cold-blast mains, etc. A decided gain has been obtained by taking care of this in blast-furnace installations.

The proof of the entire matter is that where proper constant-volume governing has been installed there has been a decided improvement in the quality and quantity of the blast-furnace output with the added advantage of a much easier means of handling the blast furnace. The proper volume of air for blowing is not left to be determined by the hit-or-miss method of the blast-furnace operator.

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No. 1618

EXPENSES AND COSTS

By H. L. Gantt, New York, N. Y.
Member of the Society

Mr. Gantt claims that there are in every manufacturing enterprise expenses which do not contribute either directly or indirectly to the production of goods. He claims that such expenses should not be considered as a part of the legitimate cost of the goods, but should be kept in a separate account.

He further claims that the expenses in this account should be classified according to their various causes, and that strenuous efforts should be made to eliminate these causes and thereby reduce this non-productive expense.

This is particularly important in time of war, when we need all of our energy for productive purposes.

INTRODUCTION

THE irresistible logic of events is making so clear the truth which is presented in my paper that it seems hardly worth while to emphasize the subject at all. Not only is it true that preventable wastes and inefficiencies will not be accepted as a legitimate part of the cost of an article, but it is also true that we may in the near future be compelled, on account of the shortage of material and labor, to deny to manufacturers material and labor unless they use them both efficiently.

With a shortage of coal, for instance, it is almost sure that the Priority Board will in the near future give preference to those plants which use their coal efficiently, and it is entirely within the bounds of possibility that those who are very wasteful in the use of coal may be denied the use of it entirely in favor of those who make better use of it.

We thus see that when labor and material are the limiting factors which determine not only our immediate welfare but our ultimate destiny as a nation, the question of efficiency in their use becomes a matter of most important public concern.

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers.

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Under these conditions the absolute necessity for an accounting system which lays bare the preventable wastes becomes evident to all, and the methods of the past which fail to do this will soon become as obsolete as a dodo.

IN determining the cost of a manufactured article, should we include all the expense incurred while that article is being manufactured, or should we include only those expenses which contribute to its production?

2 It does not require any knowledge of cost accounting, bookkeeping, or other office art to enable the practical man to say that costs should include only those expenses needed to produce the article in question, and that those people who insist on including in their costs expenses which do not contribute to the production of the article are simply trying to recover from the public through a higher selling price the expenses which they incur through inefficiency and waste.

3 All cost figures may be divided into three parts:

a The expense for material

b The expense for labor

c The overhead expense, or "burden."

4 There is no great difficulty about getting the expense for material and the expense for labor, and most concerns get these elements quite accurately, but there is a great variety of opinion as to what the "burden" charge on any particular work should be. This overhead or "burden" may be divided into two parts:

a That which is incurred through simple ownership or rental of the plant and keeping it ready for operation

b That which is incurred by operating the plant, exclusive of direct labor and material.

5 Analyzing further the meaning of the term "burden," we see that the first part is made up of ownership or rental of a number of machines or work benches, properly housed. The second part consists of the expense of operating the various machines, which consists of power, oil, waste, repairs, etc.

6 Inasmuch as the rental which we should pay for the plant is made up of the rental of the individual machines and work spaces, we must be able to determine the proper rental for each of these in order to form an intelligent idea of the proper rental for the whole plant. In the same way we can determine the amount of supervision, power, oil, and waste needed to run these machines individually.

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7 Working along these lines, we are able to determine for each machine in the factory both an idle- and an operating-expense rate.

8 Any article manufactured on a machine should undoubtedly bear the operating-expense rate for the time during which the machine was operated on it.

9 The expense of maintaining the machine in idleness during the time it was not operated cannot legitimately be charged to the work done while it was operated, and should be put into another account.

10 We thus see that every plant has two kinds of burden:

a That which produces goods and which can legitimately be charged to the cost of those goods, and

b That which produces nothing, and must be put into some other account.

11 In the past it has been too much the fashion to put these two kinds into one account and make the product bear both. This has led to so much confusion and is so evidently wrong that it is not worth discussion.

12 On the other hand, a careful consideration of the expense incurred while the plant is idle leads to very fruitful results: first, through an attempt to find out why the plant is idle, and then through an attempt to eliminate the causes of idleness, which are lack of work, lack of help, lack of material, repairs, etc.

13 Without going into the details of those subjects, it may be readily appreciated what advantages will be derived from a careful study of each of these causes.

14 This general view of the cost question leads to a further simplification of the problem which is worthy of careful consideration.

15 First, the expense of owning and maintaining a certain machine in idleness properly equipped for efficient operation should be substantially the same in any part of the country where the machine could be bought at substantially the same price.

16 Second, the amount of power, oil, waste, and repairs, and even supervision, of a certain machine should be substantially the same in any part of the country, if it were engaged upon substantially the same kind of work.

17 Following these lines of thought, we readily see that a standardization of cost methods and of costs is possible, which was unsuspected a few years ago.

18 While the writer and those with whom he has been associated have done quite a good deal of work on these lines, and while the

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results have been satisfactory to a degree that was entirely unanticipated, he does not yet feel that the matter has been developed to such a degree as to warrant detailed publication. The fact, however, that the Federal Government has placed so many contracts on a "cost plus" basis, leads him to set forth these ideas, which are the only ones which seem to him to give promise of avoiding an almost intolerable situation resulting from a complication of interests which is bound to arise in the near future.

19 It seems to the writer that much of the confusion on the subject of costs in the past has been due to a misconception of the subject. The intimate relation between production and costs has not been sufficiently recognized, and the accountant has looked upon costs as a bookkeeping proposition, whereas in truth costs are much more closely connected with engineering and production than with bookkeeping and accounting.

20 If the engineer will recognize this fact and insist that money spent without any corresponding production must be kept separate from that which was productive, either directly or indirectly, many of the apparent contradictions with which we are so frequently faced will be eliminated.

21 As soon as we establish these methods, the following question is immediately put to us by the accountant and financier, "What are we going to do with this expense of idleness?" they having never before realized that it cost something to be idle.

22 My frank answer to that is that I do not know. Moreover, I don't care, provided they do not charge it to me in the products which I buy from them. My recommendation, however, would be that they see how they can eliminate such expense by proper managerial methods.

23 I am perfectly aware that it is extremely difficult to eliminate all of such expense, but I am also aware of the fact that it is extremely easy to eliminate a large proportion of it. The solution of this problem is one of the economic questions which the war will shortly force to our attention, and I insist that it is primarily a question to be solved by engineers rather than by financiers.

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DISCUSSION

FREDERICK A. ALDEN (written). One of the most vital causes of idleness of machinery is likely to be the fact that one machine may be adapted for but one or a few operations, while if a more universal type of machine had been purchased other operations might be performed on it. In advising upon the exploitation of a new manufacture, I have always maintained that unless such manufacture was of a major type, it would be one which would cause idleness at times due to lack of demand for the finished article, as most articles have a variable demand. Hence, that unless a variety of articles could be manufactured upon the same machine with a slightly different setting, the manufacture of the article in question would not be a paying proposition. Many companies make but one or a few lines of goods or fabrications, and in consequence always have certain machinery idle at times. One remedy for this idleness would be the manufacture of auxiliary products or by-products.

Again, I have found upon inspection that many factories have machinery and stock idle which has ceased to be useful through breakage and wearing out of the former and no demand for the latter. I feel strongly that anything which cannot be used within a reasonably short time should be sold, if salable, junked if not salable, and if neither of the above is possible, converted into fuel or disposed of as rubbish. There is too great a tendency to hold on to machinery and material hoping that it may be used some day. Considering the cost of such holding, which is the cost of idleness, including storage costs, use of valuable space, further depreciation, and loss of interest on investment, a rapid and early conversion into available cash should always be the rule, based upon immediate possibilities as stated.

MAJOR FRANK B. GILBRETH commended the paper in unstinted terms and said that the average cost accountant, if let alone, would sprinkle certain costs over the entire account so that he could go to the management, particularly to the financial management, and boast of the fact that he had but a trifling amount remaining undistributed somewhere. That might be a proof of great merit among cost accountants, that they had distributed and redistributed cost items, but the more they were distributed and redistributed improperly, the more the self-deception.

Major Gilbreth then described an improved arrangement of bulletin board that would make possible a quick judgment on this

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matter, by means of which the head of a sales department with a single glance could tell which of a certain bank of machines that had been brought together on account of their mnemonic classification were going to run out of work, and could then go out and telephone to neighboring shops for immediate work, if necessary, and take on jobs which would keep down the idle time, as Mr. Gantt had pointed out. The board also showed the names of those men handling machines who had been proved to be the most efficient on them, which seemed to definitely help out the employment department in "evenizing" the necessary shifts that had to be made among the machines. The board which Major Gilbreth described was designed, he said, to show just the things that Mr. Gantt's paper had brought out.

HENRY HESS disagreed with the author that the matter under discussion was primarily a question to be solved by engineers rather than by financiers. There was a time in the history of industries, he said, when there was a sharp line of cleavage between the shop, the so-called production end, and the office, usually termed the non-productive division, each managed by specialists. That was the heyday of the engineer and producer, and the financier, as separate persons. If that period had not actually passed, it certainly was passing, and it was rather unfortunate that the author should apparently reaffirm this unfortunate division.

There should be no consideration of an important question of cost of production by the engineer as an engineer or by the financier as a financier. Any such question must be considered by both. The broad statement was made that certain expenses due to relative inefficiency of production were not part of the legitimate cost of goods. There always would be and must be some not absolutely necessary costs, the amount varying with relative efficiency of business management in a given business, and those costs must be and would be passed on to the consumer. An increase caused by an undue amount of such costs would simply lead to a refusal on the part of the purchaser to buy the goods, and therefore the consumer thus automatically applied the necessary corrective.

So far as Mr. Gantt's suggestion involved a careful subdivision of costs, it was wholly admirable, provided that each subdivision of this kind was for the purpose of its careful scanning with a view to its reduction. It was this reduction that was of importance, regardless of the allocation of any element of cost to any group of accounts.

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ADOLPH L. DE LEEUW, referring to the statement in Par. 4 that there is no great difficulty about getting the expense for material and the expense for labor, asked if, say, 30,000 tons of pig iron were bought at $14 a ton, and a year later 20,000 tons were left, and the price of pig iron had gone up to $58 a ton, what was the expense of the material? If it was said that the material should be charged at $14 a ton, well and good; but if the 30,000 tons gave out, and 30,000 tons were purchased at $58 per ton, on the expectation that it would go up to $80 in the near future, but instead the price went down again to $14 a ton, then what would be the price of the material? $58? But who would buy the product on the basis of $58 for pig iron?

There was no question about the advisability or the desirability of keeping a plant working, but in the plant with which he was connected there were large portions of the buildings devoted entirely to special operations, and each machine used was good for one operation and one piece only and for nothing else. Furthermore, even if they did not increase the capacity, and should run the shop 50 hours a week, they all knew there were 168 hours in the week. Was this machinery idle for the other 118 hours? If it was not and the shop ran overtime, then was it idle or negatively idle?

A. L. WILLISTON said that most manufacturers he had come in contact with seemed to regard overhead as one of those mysterious things that could not be analyzed, — that it was necessarily a constant. It was not a constant, and Mr. Gantt had called attention to one of the variables that affected it. A very large percentage of all the confusion in the matter of accounting had been due to the fact that we were in the habit of expressing costs in figures and we had been confused in thinking that costs which were expressed in figures were a constant. There was hardly a single item of cost in any manufacturing operation that was a constant, and we should get into the habit of thinking of these things as variables, studying the laws of their variation, instead of thinking of them as constants and trying to memorize those constants.

WALTER N. POLAKOV thought that the points raised by previous discussers were relatively unimportant compared with the big question: If it costs us something to do nothing, why should society at large pay for our inefficiency and for our idleness? In England and France

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and Italy the slogan was, "The idle hand assists the enemy," and we might equally well say that the idle machine assisted the enemy, because the fact was that if we left our machinery idle or inoperative the results were the same as those due to the sinking of our ships, the blowing up of munition factories or the burning of grain elevators.

His work in the public-utility and power-plant field, he said, had been such as to make him believe the idleness question was just as important, if not more so, in that particular branch of industry as in others. Mr. Polakov then had projected on the screen a chart representing averages obtained from some seventeen power plants and showing that but half the capacity was utilized on the average daily run.

CARL G. BARTH called attention to the fact that twenty-five years ago Frederick W. Taylor had covered everything that had been brought up by the previous speakers, and that he had done as much for accounting as he had in the management of the plant and in other details. It was his hope that he could eventually give the world the benefit of what Mr. Taylor did.

Mr. Barth said he considered that the first essential of a cost system was that it in some way or other accounted for every penny spent, whereas most concerns simply use an inherited or appropriated burden factor. Thus his way of introducing a cost system in a plant consists in first establishing interlocking costs in the simplest way possible, namely, by distributing a thoroughly analyzed burden on labor only, regardless of departments. After running this way for a short time he takes the first steps toward ultimate refinement by departmentalizing the burden, but still distributing both the general part of the burden and the departmental burdens on labor, each department thus having a burden factor of its own, which is the sum of the "general labor burden" and its own "local labor burden." Finally he makes the ultimate refinement as practised by Dr. Taylor, of distributing the local burden of each department, increased by a share of the total burden of all supporting or auxiliary departments, through the machine and other work-place hours of each department, retaining the labor distribution of the general office and administrative burden.

The expense of idleness, which Mr. Gantt stated he did not know how to dispose of, Mr. Barth said automatically found its way to the profit and loss account.

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H. M. WILCOX said that in the standardization and wage-payment systems which had been developed, attention had been concentrated almost entirely on productive labor.

He could say from personal experience that a very complete analysis of idle-machine time had shown the Winchester Repeating Arms Company where it could eliminate a great deal of lost time, and in a great many instances they had been able to establish standards and definite forms of wage payment other than day pay to compen-

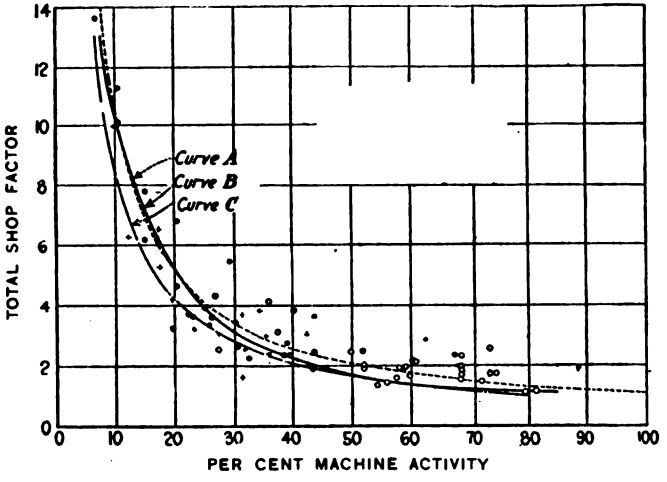

FIG. 1 RELATION BETWEEN MACHINE ACTIVITY AND TOTAL SHOP FACTOR

(48 hours per week = 100 per cent activity)

Curve A: — Plotted from monthly reports of May, June and July, 1917.

Curve B: — Geometric equilateral hyperbola of equation $xy = 100$, where x = per cent machine activity and y = shop factor.

Curve C: — Theoretical equilateral hyperbola of equation $xy = 80$.

sate their so-called non-productive workers for what they had done in limiting the idle time of equipment and organization.

As to the effect of idle-machine time on cost, from their present data, covering six or eight months, they had plotted the curve shown in Fig. 1, and had found that the average curve drawn through all the points, amounting to several hundred, was an equilateral hyperbola. The shop factor was taken as the burden earned by the machinery at machinery-hour rates divided by the actual burden charged against the various shops. The first 5 per cent of idleness, it would seem, had little effect on the cost; the next 10 per cent had more,

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and the more inactive the machinery became the more rapid the losses were. In the reconstruction period after the war this question of idle-machine time would be one of very vital importance.

THE AUTHOR, in closing, said he had suggested the year before that the expense of idleness might be put in profit and loss, as mentioned by Mr. Barth. He did not care whether this was done or not. If one man put it on profit and loss and the other put it on his product and based his selling price on the cost of his product and the other did not, the one who did not would not sell his goods in competition with the other man, and then he would have more of his plant idle and more of this item to consider.

Two years ago a man had told him the cost on a certain article was 30 cents a dozen and that they could be bought for 26 cents a dozen, and had asked him whether to buy them or make them. The cost consisted of 8 cents a dozen for material, 10 cents for labor and 12 cents for overhead, and the plant was running one-third full. On being told that the overhead if the plant ran full would be about 5 cents a dozen, he had said to the man that if the plant was run full the cost would be 23 cents instead of 30. A competitor running full time would have less cost and so would sell where he could not, making the man's cost go up more because he would have still more idle time.

Mr. Hess had been more fortunate than he in the fact that the financiers had not interfered with the operation of his plant. His experience was that as soon as the engineer began to show the plant was being interfered with by the financier who did not know anything about manufacturing, then the trouble began.

If we could show those expenses attributable to management and mismanagement, and show where they belonged instead of placing them on the workmen, we could soon make the salesmen and the financiers sit up and take notice. It had been done in a number of cases, and no one who was using this method would think of giving it up.

So high an authority as the Chief Constructor of the United States Navy, referring to the author's paper presented at the 1916 Annual Meeting on this general subject, had said that it was the only system he knew anything about which would do justice to the arsenals and the navy yards.

In regard to Mr. De Leeuw's questions, no general answer could be made. There were some present who had been wrestling with these questions for the past two years, and they were satisfied

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with the answers they had reached. The answer would not be the same in different plants. He would not think of a set of rules to go by, for rules without fundamental principles were as misleading as they could be. If we got the fundamental principles right and could not work out rules, we were on the wrong job. If we worked out the fundamental principles and could not apply them, we must get something to help us. In the past we had tried to run things according to precedent and by rules; and we had reached the end of it. The old business schemes did not work any longer. It was necessary for us to eliminate waste and expense, and not cover them in the product and give them to the public to digest. If we attempted to digest them we should be beaten by Germany.

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No. 1619

BY-PRODUCT COKE AND COKING OPERATIONS

By C. J. Ramsburg [1] and F. W. Sperr, Jr.,[2] Pittsburgh, Pa.
Non-Members

After discussing the notable events in the history of by-product coke making in the United States since the introduction of the process in 1906, the authors give a brief account of the generally accepted theory upon which the latter is based. They then take up the subjects of shape and structure, and present a standard method which they have devised for the grading of coke according to its cell structure. Photographs are included which show the structure of cokes that have given successful results in blast furnaces and foundries in various parts of the country. The combustion of coke in the blast furnace is then considered with reference to the size and grade of the fuel, and the paper concludes with a description of methods employed in eliminating sponge and in overcoming too great density in cell structure.

ON January 1, 1915, there were in operation 6438 by-product recovery ovens of various sizes in the United States and Canada, having a capacity to carbonize 24,000,000 tons of coal per annum, and to produce therefrom approximately 18,800,000 tons of coke. Despite the fact that in the interim practically five hundred ovens have been discarded, on January 1, 1918, there will be in operation, if present contracts are completed, 9900 ovens, having a capacity to carbonize 47,400,000 tons per annum, giving a coke production of 35,000,000 tons. In this three-year period by-product coke production will have practically doubled, and there will have been as much gain in capacity as in the previous twenty years.

2 The cause of this rapid increase has not been a desire to take advantage of the inflated prices for by-products due to war conditions, but a financial condition favoring large investments brought about by the war, and making it possible to carry forward plans made previously.

[1] Second Vice-President, The H. Koppers Company.

[2] Chief Chemist, The H. Koppers Company.

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers. Contributed by the Philadelphia Section.

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3 The most impressive fact is the conservation of our coal supply brought about by the introduction of modern methods. It may be of interest to make a few calculations simply from the standpoint of *fuel values;* and to put the matter on the most conservative basis possible, let us figure such values in terms of coal.

4 Table 1 shows a total fuel saving of 825 lb. of coal per ton of furnace coke. The fuel value of the gas is put as against raw *coal*, B.t.u. for B.t.u. There is a further saving in the blast furnace of

TABLE 1 BY-PRODUCT YIELDS FROM COAL SUCH AS IS NOW USED TO MAKE FIRST-CLASS BY-PRODUCT COKE IN THE MIDDLE STATES DISTRICT, PER TON OF COKE MADE

85 PER CENT HIGH-VOLATILE, 15 PER CENT LOW-VOLATILE

		Fuel-value equivalent, lb. of coal
To make 1 ton of Furnace Coke, 1.4 to 1.5 tons Coal are Required. By beehive coking, the by-products wasted have a fuel value equivalent to 625 lb. of coal.	*Surplus Gas. 9000 cu. ft., 550 B.t.u. per cu. ft.* Used as fuel.	350
	Tar. 12 gallons. Used to make creosote oil, pitch, lampblack, various oils and dye materials.	133
	Ammonium Sulphate. 33 lb. (or, in form of 25 per cent ammonia liquor, *33 lb.*). Used for fertilizer, for refrigeration, and for nitric acid and other chemical manufactures.	(*No fuel equivalent*)
	Benzols (as light oil). *4.5 gallons.* Used for explosive bases, motor fuel, dye-material bases, phenol and other chemical manufacture, and as a solvent and cleanser.	42
	Coke Breeze. 120 lb. Used as fuel.	100
	Total	625
	Add coal equivalent wasted in beehive oven	200
	Total economy of by-product oven per ton coke	825

200 lb. of coke per ton of beehive coke formerly used. Figured back on a coal basis, these 200 lb. of coke represent 282½ lb. of coal at the beehive oven, so that the total saving amounts to approximately 1100 lb. of coal — 0.55 ton — for each ton of by-product coke made in the modern plant. Since the ovens added from January 1, 1915, to 1918 will produce practically 16,200,000 tons of coke per annum, it follows that they will save annually the fuel equivalent of 9,000,000 tons of coal.

5 Looking backward over the years consumed in bringing the coke oven to its present stage of development in America, there are some events which stand out preëminently. The first of these

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dates back to 1906. In that year the United States Steel Corporation was brought face to face with the necessity of formulating a definite policy as to its coke supply, and appointed a committee to study beehive coking and by-product coking and to make a recommendation to the company. The advice of this committee was quickly acted upon by the corporation in the decision to build a by-product oven plant at Joliet, Ill., in connection with the blast furnace and steel plant of the Illinois Steel Company, and to build that type of oven which they had found to give the most efficient results in European countries.

6 The success of this Joliet plant was so immediate that the corporation without delay proceeded with the construction of additional plants of the same type, including the largest by-product coke plant in the world at Gary, Ind., consisting of 560 Koppers ovens, and a plant of approximately the same size as the Joliet plant (280 ovens) at Ensley, Ala., for the Tennessee Coal, Iron, and Railroad Company.

7 The second event was the selection of silica material for one of the oven batteries at Joliet. The value of the silica in this connection is due to four characteristics:

a The conductivity at high temperatures is superior to that of clay brick

b The fusing or softening temperature is much higher than that of fireclay

c The action under heat may be calculated with scientific exactness, due to its practically constant composition

d The expansion and contraction of silica material between 2000 and 2600 deg. fahr. is practically negligible, so that when the material has once been heated to within this temperature range (under which condition the coking operations are conducted) no further appreciable movement takes place.

8 The third event was the realization that with uniform heat distribution in the ovens and with the use of silica material much higher heats and consequent higher coking velocities could be employed, and, further, that, with the lower coking periods, higher volatile coals could be used, with increased yields of by-products and equally satisfactory coke.

9 The result can be demonstrated by the fact that the Joliet plant of the United States Steel Corporation, put into operation in

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1908, was originally planned to use from 70 to 80 per cent of low-volatile coal, and the coking time was figured at 24 hours. A coke plant of 640 ovens, now building at Clairton, Pa., near Pittsburgh, is so designed that it may be operated on 15 hours' coking time and is expected to use 100 per cent high-volatile coal. Even if this does not make quite as high-grade furnace coke as the coke at Joliet, its use will work out on broad lines to better purpose, and time will tell where the comparison lies after opportunity has been given the furnace operators to adjust themselves to the new type of coke. The effect on the products can best be shown by reference to Table 2.

TABLE 2 YIELDS OF BY-PRODUCTS PER TON OF COKE

	Coal mixture A 80 per cent low-volatile 20 per cent high-volatile	Coal Mixture B 100 per cent high-volatile
Tar	6.5 gal.	13.5 gal
Ammonium sulphate	23.3 lb.	38.0 lb.
Surplus gas (debenzolized)	7500 cu ft.	10,000 cu. ft.
B.t.u. per cu. ft. gas	500	560
Total B.t.u. in surplus gas	3,750,000	5,600,000
Light oil (benzols)	2.6 gal.	5.4 gal.

10 A comparison in value of by-products on a basis of normal values shows a credit per ton of furnace coke of approximately $1.25 in favor of the high-volatile coal.

11 The fourth event was an awakening to the fact that, while an increase in the cubical content of an oven tends to a reduction in plant cost and in operating labor due to handling larger units, a decrease in oven width would more than offset this unit-size advantage because of absolutely different conditions.

12 The reason for this becomes apparent with an understanding of the factors involved. Increased length of oven gives increased cubical content, and the ultimate economic length depends upon the mechanical and structural limits. Of increased height the same may be said, except that this involves questions of time of contact of volatile products and speed of their flow which modify the advantage and which are yet to be finally worked out.

13 Increased *oven width* involves an entirely different consideration. Practically all the heat supplied for the coking of the coal mass flows from the two walls toward the center. This flow of heat depends to a large extent on the resistance and temperature, and

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in the coke oven the average rate of coking depends, of course, on the rate of heat penetration. For example, it becomes apparent at once, in a comparison between a 16-in. oven and a 20-in. oven, that the following is true:

a With the same temperature of wall the average velocity of coking in the 20-in. oven will be less than in the 16-in. oven, and the time required to coke the 20-in. oven will be more than proportionally greater than the 16-in. oven

b To coke the 20-in. oven in the same time as the 16-in. oven, the wall temperature must be increased very markedly

c To coke the coal in the two ovens at the same average rate, the wall of the wider oven must be considerably hotter than that of the narrower one

d With the *same wall temperatures*, more coke can be made per day in the narrower oven than in the wide one

e To make the same amount of coke per day, the wall temperature in the 16-in. oven would be lower.

14 Four points are of great value in this connection:

a Overcoked material is of less value in a furnace than a greener coke

b The wider the oven the more overcoked the outside layers will be and the larger the proportion of overcoked material for a given output

c The production of by-products is enhanced by reducing the wall temperatures

d The life of oven brickwork is increased by being operated at lower temperatures.

15 The result of this reasoning was the decision, in 1914, to reduce the width of oven from 19¾ in., the average then being built, to 18¼ in. Plants of the reduced width are now in operation as follows:

	Ovens
Toledo Furnace Company	94
Youngstown Sheet and Tube Company	204
United Furnace Company	47
River Furnace Company	204

16 There is no doubt among those who have been acquainted with the wider ovens that the narrower oven has the following distinct advantages:

a Less sponge in the coke

b Better coke from the same coal

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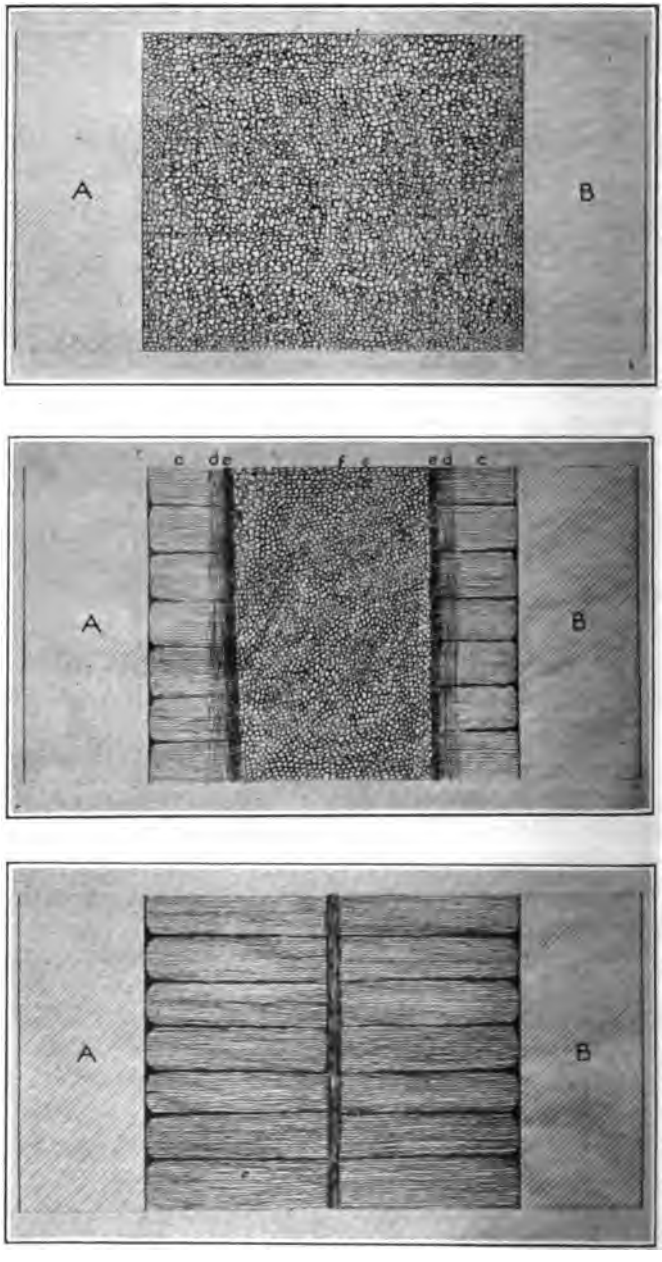

FIGS. 1-3 DIAGRAM OF THE COKING PROCESS

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c As good coke from higher volatile mixtures
d Higher yields of tar, ammonia, and benzols
e Low temperatures for the same coking velocity.

17 The fifth event in coke-oven development is the universal recovery of benzols. The war furnished the primary inducement to developing this phase of the industry; but the fact that the material might be disposed of advantageously for motor fuel after the demand for explosives would cease had an important bearing in stabilizing the large investments demanded.

18 Previous to the war comparatively few plants were equipped for benzol recovery; in fact, outside the plants of the Semet Solvay Company, operated for their own account, there was comparatively little benzol extracted, and this was used, for the most part, in enriching illuminating gas. Today practically every coke-oven plant in America has installed this recovery, and the production in 1917 will be in excess of 40,000,000 gal., rated as light oil, if continued at the present rate.

19 While the removal of benzol reduces the heat units in the gas, the loss in this manner is a very small factor, and the return to be secured from the sale of this product is likely to be greater than that secured from the recovery of tar.

20 One feature of the benzol credit as related to motor fuel is the smallness of the quantity compared with gasoline production, and, since benzol and gasoline are miscible, the utility of benzol will be enhanced by increasing the quantities available.

21 Experiments recently conducted by a large oil company on its trucks and passenger automobiles proved that not only is benzol more valuable than gasoline as a motor fuel when used straight, but its effective value is increased by being mixed with gasoline. While these experiments are not complete, nevertheless they indicate that a mixture of equal parts of gasoline and benzol gives a value over 16 per cent greater than that of straight gasoline, which shows 32 per cent increased value for the benzol half. In 1917 there will be produced in this country over 1,000,000,000 gal. of gasoline, so, while the value of benzol is stabilized, for this reason it cannot be a very great factor in the motor-fuel situation. Every means should be taken not only to secure additional quantities from a standpoint of *preparedness*, but from a standpoint of motor-fuel supply.

22 In connection with the value of benzol as a motor fuel there is an interesting fact which may in the future have a very marked influence. In many quarters alcohol is looked upon as the ultimate

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fuel, but it cannot be employed except with less efficiency and with greater difficulties, due to its high oxygen content. Commercial alcohol and gasoline are not miscible. Alcohol and benzol are miscible and make a most efficient fuel, and, further, *after the addition of benzol to alcohol* the mixture will carry quite a high proportion of gasoline. The future may see benzol as the tie between gasoline and

FIG. 4 COKE IN BY-PRODUCT OVEN JUST AFTER REMOVING DOOR

alcohol, permitting a piecing-out of the gasoline supply and an introduction of alcohol as a commercial motor fuel.

23 Taking up in somewhat more detail the study of by-product coke and its use in blast furnaces, the phenomenal growth of the by-product industry has stimulated a renewed interest in the main product. This interest is due, first, to the recent revolutionising

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of ideas regarding the relative values of by-product and beehive coke. The tardy recognition of the fact that by-product coke of a fairly wide range of origin, when properly used in the blast furnace, gives results not merely as good as, but much *superior* to, those obtained from beehive coke, was accompanied by a realization that the limit of efficiency had by no means been reached; that Grüner's "ideal performance" — long the *ne plus ultra* of blast-furnace men — was actually being surpassed by many blast furnaces, and that much regarding the question of coke economy still remained to be learned. In the renewed study of the subject that this realization is just beginning to stimulate, we have the inestimable advantage that the by-product coke plants are being located in proximity to, and usually under the same management as, the blast furnaces that they are intended to supply, instead of at the coal mines as was the case with the beehive ovens. Thus the blast-furnace operator knows better the sources of the material that he has to use and the conditions under which it was produced, while the coke-plant operator can more intelligently regulate the performance of his ovens and the quality of his product, according to the requirements of the furnace. Above all, the combination and coöperation of the two plants result in a regularity of performance that is perhaps more to be desired than any specific quality of material. It is to be hoped that this coöperation may soon be extended to the foundry and other industries using coke as fuel.

24 It will assist in following the few descriptive studies of coke that we have to present, to give a brief account of the generally accepted theory of the coking process. The development of this theory is due to several German investigators, notably Muck,[1] Hilgenstock,[2] Rau,[3] and Simmersbach,[4] and it has received such abundant confirmation from every practical standpoint that there can be no question of its soundness.

25 Let Fig. 1 represent a section across a by-product coke oven immediately after the charge of coal is introduced. The layer of coal next to each wall *A* and *B* is very rapidly heated. A complicated process of destructive distillation begins, and at a temperature of about 375 to 400 deg. cent. the layer becomes soft and pasty. The pasty mass is for a while in a state of violent ebullition, due to the

[1] Chemie der Steinkohle.
[2] Journal für Gasbeleuchtung, vol. 45, (1902), p. 617.
[3] Stahl und Eisen, 1910, p. 1240.
[4] Grundlagen der Kokschemie, Berlin, Julius Springer, 1914.

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rapid expulsion of its volatile matter, and then rapidly solidifies, the indurated residue retaining the vesicular form and structure of the pasty, foaming stage.

26 The adjacent layer toward the interior has in the meantime reached the pasty stage, the fusion being assisted by the penetration of some of the soft material forced over from the outer layer. The gases and vapors follow always the line of least resistance and pass through the porous outer layer and up along the wall of the oven instead of forcing their way through the viscous inner portion of the fused layer, and then through the mass of coal. In passing through the highly heated porous layer, the hydrocarbons undergo a partial secondary decomposition, depositing part of their carbon on the cellular surfaces just formed, thus building up and strengthening the coke. The coking process is thus to be conceived as involving the formation of a fused zone, and the gradual advance of this zone toward the center of the oven, the evolved gases and vapors depositing part of their carbon in the vesicular mass left as the zone progresses. The condition of the material in the oven when the coking has fairly well advanced may be represented by Fig. 2: *c* is the portion already coked, *d* is the fused zone merging into an adjacent zone *e*, which, being in a state of incipient fusion, is more viscous; *f* is the uncoked coal.

27 The actual thickness of the fused zone is probably not over ½ in. The drop of temperature across this narrow zone is very great, and the interior of the oven remains comparatively cool, even at an advanced stage in the coking process. Simmersbach's experiments[1] on a Koppers oven of 500 mm. (19⅞ in.) mean width, operating on 29 hours' coking time with a final maximum temperature of 1120 deg. cent., showed that the temperature in the middle of the oven, 1 meter above the floor, remained about 10 deg. cent. for 2.5 hours after charging; then rose to 100 deg. cent., and remained at this temperature until 13 hours after charging. At 20 hours the temperature was only 410 deg. cent.

28 The rate of advance of the two zones toward the center of the oven depends principally upon the temperature of the walls *A* and *B*. In present practice, with ovens 18 in. wide and wall temperatures about 1000 deg. cent., the average rate is about ½ in. per hour. The initial rate is, however, much more rapid than this, and decreases as the center of the oven is approached.

29 As the coking progresses, cracks or joints develop perpendicular to the walls of the oven, thus determining the blocks of coke

[1] Stahl und Eisen, June 14, 1914, p. 954.

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as they are eventually formed when the oven is discharged. These cracks form avenues of escape for a large percentage of the gases,

FIG. 5 BLAST-FURNACE COKE, ATLANTIC DISTRICT

FIG. 6 TYPICAL BY-PRODUCT COKE

hence the amount of deposited carbon is greater in proportion on the surfaces of the blocks than in the interior. Eventually the two zones

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merge at the center of the oven (Fig. 3), and, with the practically complete expulsion of the last of the volatile matter, the coking process is finished. There is always a distinct parting in the center of the oven, so that the length of the blocks is equivalent to about half the width of the oven. Fig. 4 shows a view of the coke as it appears when the door of the oven is removed. Most of the coke immediately adjacent to the walls of the oven is covered with a skin of carbonized pitch. The true form of the blocks may be seen in a few places where this has been broken away.

30 Fig. 5 shows a view of a typical coke. In this figure the individual blocks may be seen distinctly. A few characteristic blocks are shown in Fig. 6. The three smaller pieces in this figure are cross-sections. The end of the block (Fig. 7) originally adjacent to the wall of the oven may always be distinguished by its cauliflower-like appearance and dense layers of deposited carbon. We shall designate it as the wall end and shall call the other extremity the center end, for want of better terms. The structure of the coke toward the center end is always more open, and occasionally is somewhat spongy.

31 The shape of the coke is quite characteristic, depending upon the coal from which it is produced, and also, to a considerable extent, upon the method of heat treatment. The coke-oven man classes his product as either *blocky* or *fingery*, coke of the former character being preferred. Some typically fingery coke is shown in Fig. 8. As a rule, the coke from coals of over 30 per cent volatile matter is apt to have a fingery tendency — and this becomes highly pronounced if the coal has a high oxygen content. By coking such coals very slowly at temperatures somewhat lower than used in ordinary practice, the fingery tendency may be disguised or in many cases entirely eliminated. By disguising it, we mean that the product will actually appear to form large, massive blocks, but these blocks, if closely examined, will be found actually to be bundles of slender pieces more or less firmly cemented together. However, if the heat treatment be very carefully regulated during the coking process — especially in ovens designed and adapted to this particular type of coal — genuine, firm, blocky coke may be made from many coals usually regarded as producing only the fingery variety.

32 The size of the blocks is affected to a certain extent by almost all the conditions pertaining to the manufacture of coke. The length is, of course, dependent upon the width of the oven, the average being, on account of shrinkage, a little less than half the

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width of the oven. The blocks from the top of the oven are usually (especially with high-volatile coals) shorter than those from the

FIG. 7 WALL END OF A BLOCK OF COKE

FIG. 8 FINGERY COKE AND SPONGE (COLORADO COAL)

bottom. Overcoking and high temperatures tend to produce small-sized coke.

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33 Coming now to an examination of the natural surfaces of the blocks, we may, in the first place, disregard the color as being relatively unimportant. It depends largely upon the method of quenching, and, to some extent, on the quality of the water used, the use of large amounts of water causing a dark color, while with the careful use of a minimum quantity of water a light gray color can always be preserved. The majority of cokes produced from the

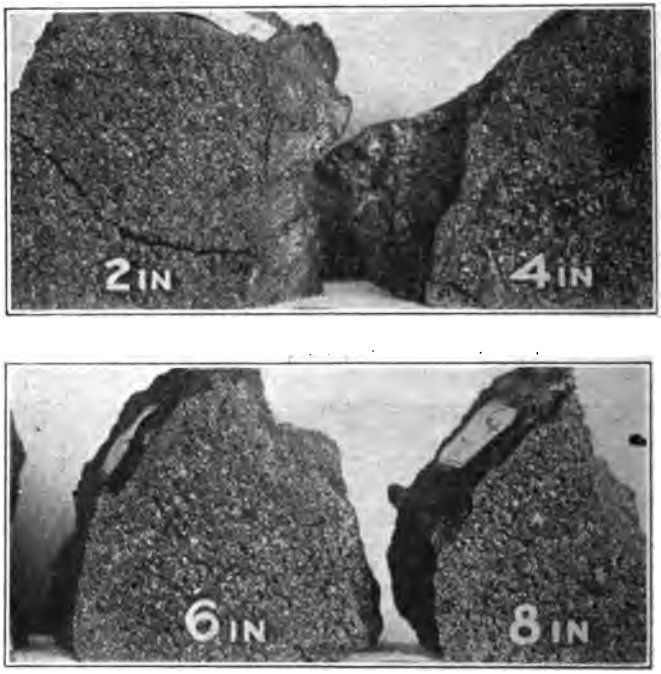

FIG. 9 CROSS-SECTIONS OF COKE SHOWING SURFACES TOWARD CENTER
(At marked distances from wall)

standard coking coals rich in hydrocarbons and low in oxygen have close-textured, even surfaces, with possibly a few narrow, transverse zones of slightly larger cell openings interspersed between the two extremities. Many cokes from coals of the Connellsville (Pa.) type show the same silvery, glossy skin that used to be so much prized in beehive coke. This is probably indicative of a very heavy deposit of carbon, especially favored by slow and uniform evolution of a very rich gas.

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34 Other cokes fully equal in value to the above are characterized by a peculiar shaggy appearance, as if they were covered with blotches of dark moss. This appearance is usually found in cokes produced from mixtures of eastern coking coals with the somewhat more highly oxygenated coals of the central field. Oddly enough, both types of coal usually make smooth coke if carbonized separately.

35 Certain cokes present transverse pebbly seams — usually not more than two or three. These seams are very narrow and

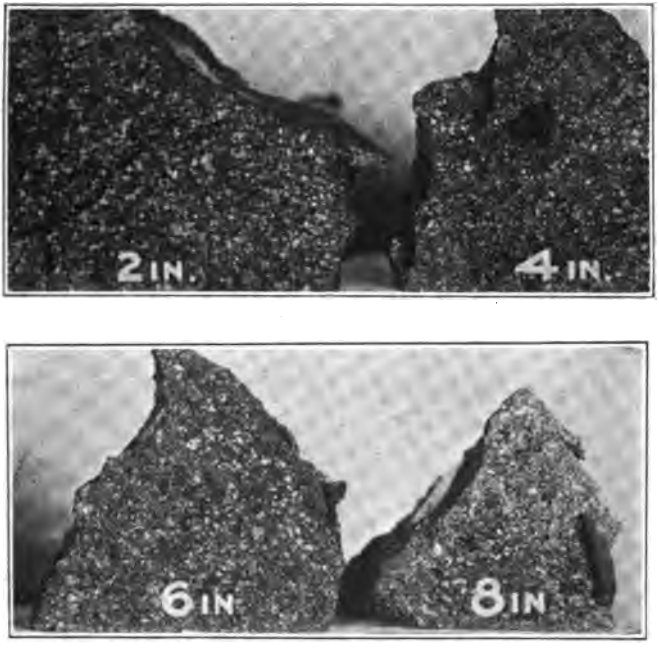

FIG. 10 CROSS-SECTIONS OF COKE SHOWING SURFACES FACING TOWARD WALL
(At marked distances from wall)

quite coherent, and may be shown to be composed of small globules of quite pure carbon, with no apparent cellular structure. This phenomenon again appears to be characteristic of the more highly oxygenated coals.

36 The surfaces always show more or less transverse and longitudinal cracks, significantly at right angles — either parallel or perpendicular to the wall of the oven. Naturally these are an element of weakness, and their presence to an excessive degree is

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one of the surest "first-hand" indications of an inferior grade of coke that we have. The amount of fracturing can be controlled to a surprising extent by proper methods of heat treatment.

37 By breaking a piece of coke and examining the fresh surfaces we find revealed the cellular structure that is characteristic of all cokes and which cannot be seen in its true development simply by inspecting the dense natural surfaces. No definition of coke is complete that does not take this cellular structure into account.

38 The usual way — and the easiest — to examine the cell structure is to break a piece of coke crosswise and note the appearance of the fresh surfaces. Great care must, however, be taken, in comparing one coke with another by this method, to break the pieces at approximately the same distance from the wall end, since the cells are likely to increase considerably in size from the wall to the center. Oddly enough, in many cokes there is a characteristic difference in the two surfaces of a break. No matter where the piece is fractured, the surface on the wall side has always a granular appearance, with a steel-gray luster and well-defined cell openings. The opposite surface (i.e., looking toward the center of the oven) has a characteristic graphitic luster, with the cell openings flatter and possibly not so sharply defined.

39 Although this difference is rather hard to depict photographically in a satisfactory manner, we have attempted to do so in Figs. 9 and 10, which will also show the variation of the sizes of cells from wall and to center. The sections have been made with a $\frac{1}{16}$-in. emery wheel at 2, 4, and 6 in. from the wall end of one block of coke. (This is a standard blast-furnace coke made from a mixture of West Virginia and Pennsylvania coals, and is the same as shown in Fig. 13.)

40 For any accurate comparison of the cell structure of different cokes we prefer to make longitudinal sections with a thin emery wheel — such sections as are shown in Figs. 12 to 17. If this is done, the danger of confusing sections made at different distances from the wall will be largely eliminated. It must be mentioned that *breaking* a piece of coke longitudinally so as to reveal the real cell structure is a decidedly difficult matter. Almost always the break will be found to be made along the plane of a natural longitudinal fracture, and the exposed surfaces will be found to be covered with deposited carbon.

41 Great importance has been attributed to the cell structure of coke by all authorities on the subject, and especially by blast-furnace operators, and yet the subject is very poorly defined and no standards of comparison have been established. We have recently

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begun the use of a simple system, analogous to the scale of hardness used in the study of metals, which we hope may come into general

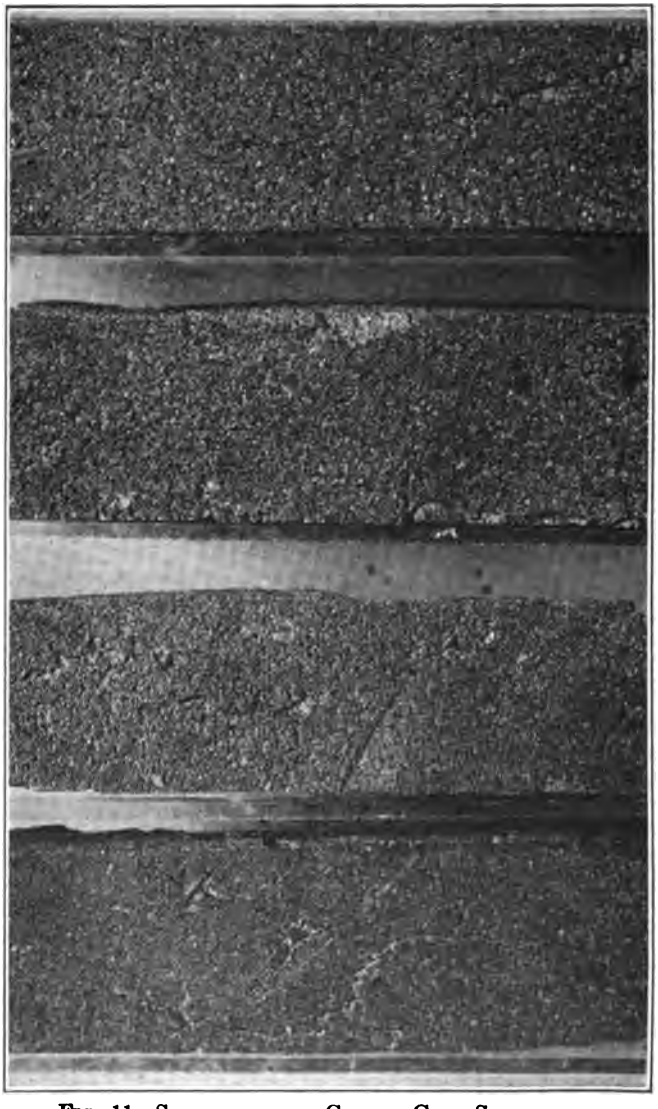

FIG. 11 STANDARDS FOR GAGING CELL STRUCTURE
(No. 1 at bottom; No. 4 at top)

favor. At present we employ a set of four standards, shown in Fig. 11. These are all longitudinal sections, cut from blocks of typically

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different cokes. The sections are the same length, and each is cut beginning 1½ in. from the wall end. The sections are numbered 1 to

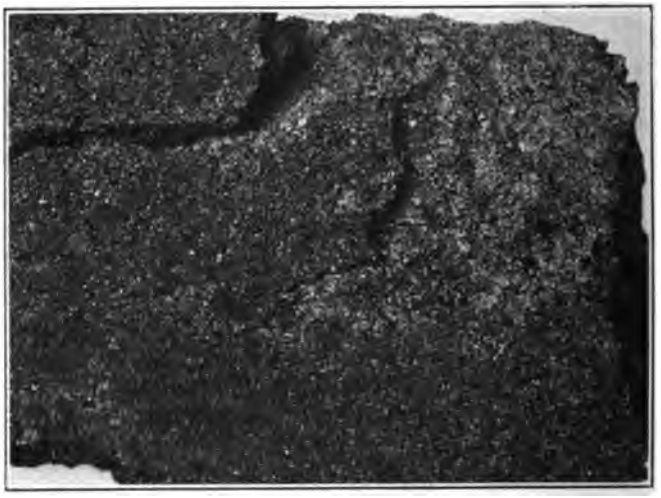

FIG. 12 COKE FROM ELKHORN COAL, WITH 35 PER CENT POCAHONTAS

FIG. 13 COKE FROM MIXTURE OF PENNSYLVANIA AND WEST VIRGINIA COALS

4 in order of increasing cell size. With such a set of standards it is easy to grade any coke according to its cell structure, and the grading will convey a much more definite idea than the loose terms of "dense,"

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"close," "rather close," "fairly open," "medium," etc., hitherto used.

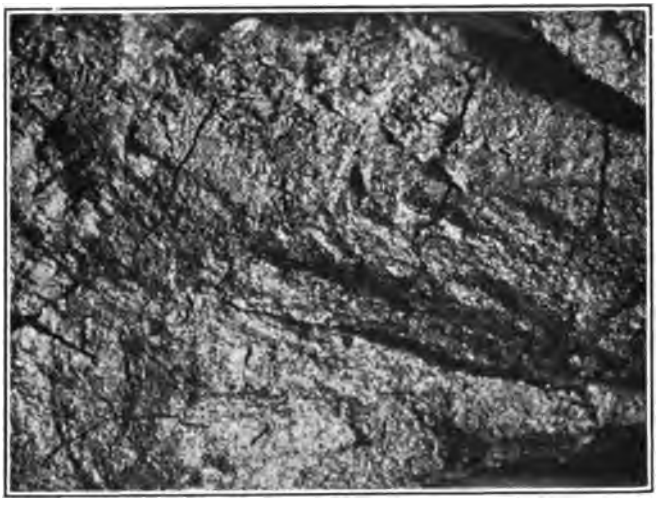

FIG. 14 COKE FROM ALABAMA COALS

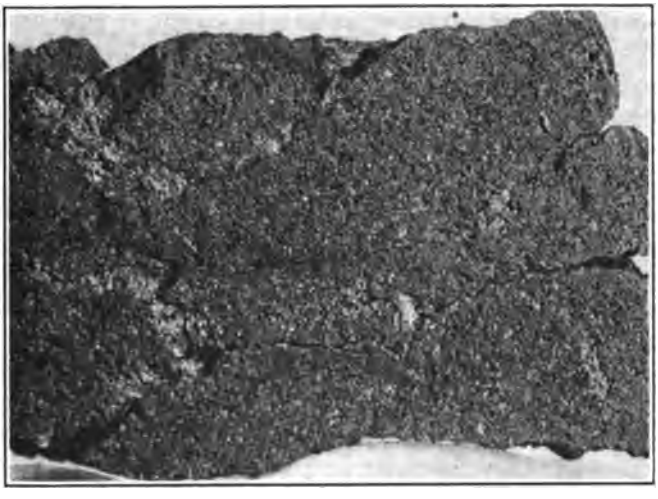

FIG. 15 COKE FROM KENTUCKY COAL, WITH 15 PER CENT POCAHONTAS

42 In addition to grading cokes according to size of cells, we may also classify them as regular or irregular in cell structure. The

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standards would all be considered as regular in structure. This does not mean at all that the cells are of the same size, but their general arrangement gives an easily perceived impression of regularity. What we mean by irregular structure is illustrated by the sections shown in Fig. 12. This sort of coke has alternate patches of close and open texture, and is frequently produced by the more highly oxygenated class of coking coals, as well as by mixtures of coals having decidedly different characteristics.

43 It might possibly be thought now that an interesting table could be prepared grading the cell structure of cokes produced from various typical coals. Such a table would be well-nigh valueless unless the data were carefully qualified by details regarding preliminary treatment of each coal, dimensions of ovens, temperatures, coking time, and several other factors, each of which plays a part in the development of cell structure. It may be more profitable to show a few sections of different cokes that have given successful results in blast-furnace and foundry practice in various parts of the country. Figs. 12 to 17, inclusive, illustrate some specimens carefully selected to be as representative as possible.

44 Sometimes too much reliance is placed in the determination of the specific gravity and porosity of coke. Figures as to porosity or the percentage of cell space in the total volume of coke are almost valueless unless supplemented by an examination of the actual size of cells and thickness of cell walls. A coke of close texture and thin walls may have the same percentage of cell space as one having large cells and relatively thick walls. As John Fulton[1] the pioneer investigator of coke, said, 34 years ago: "Mere cellular space . . . cannot be used as an element in the practical determination of the value of cokes for blast-furnace use. Furnace gases cannot act on cell spaces; they can only act on exposed surfaces." It is the cell walls and surfaces that are the most important. Cell space and porosity, which is the measure of it, are merely incidental.

45 Table 3, which gives the specific gravities and porosities of coke specimens, will show that there is really no relation between cell structure and porosity.

46 For ordinary purposes in grading cell structure magnification is unnecessary. Photographic enlargement gives some interesting information as to the character of the cell walls. Figs. 18, 19, 20 and 21 show portions of standards Nos. 1, 2, 3, and 4, respectively, each enlarged 10 times. There is considerable apparent irregularity

[1] Bull. Am. Inst. Min. Eng., October, 1883.

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of cell diameter, due to the fact that the cells are cut in different planes, but the comparison of the four types of coke is fairly good.

47 In passing from this subject of the examination of coke sections we would take occasion to point out the interesting field open here for the application of petrographic methods to an exhaustive investigation of the material. The actual chemical and physical state of the carbon produced from various coals under various conditions is an important matter from a practical standpoint. Differences in the true specific gravity of coke are frequently found that cannot be explained by variation in the content of inorganic matter. The actual condition of this inorganic matter after carbonization, the amount of reduction of the various oxides, the possible effect of the

TABLE 3 SPECIFIC GRAVITIES AND POROSITIES OF COKE SPECIMENS

Cell grading	Figure	Apparent specific gravity	True specific gravity	Porosity
1 (Standard)	11	1.097	1.917	42.8
1	.....	0 924	2.006	53.7
1.5	12	0.974	1.891	48.5
2 (Standard)	11	1.007	2.028	50.4
2	14	1.138	1.948	41.6
2 5	.....	0.857	1.979	56.7
3 (Standard)	11	1.071	1.831	41.6
3	16	1.053	1.917	45.1
3	17	0 854	1.862	54.1
4 (Standard)	11	0.943	1.988	52.6
4	13	0.943	1.988	52.6
4	15	0.917	1.921	52.3

finely disseminated mineral matter in strengthening or weakening the cell walls are all very important. Inorganic matter does not necessarily constitute an element of weakness. Large particles, especially if segregated, are injurious, but finely divided mineral matter may actually strengthen the cell walls. High-ash cokes are frequently stronger than low-ash cokes from the same kind of coal. Some experiments in washing and coking coals of moderate ash content have shown that where the original coal gave a strong coke, the washed coal gave a weaker coke, the difference being undoubtedly due, to some extent, to the removal of some of the mineral matter, although the high moisture content of the washed coal might have had some effect. Simmersbach gives some evidence to show that iron present in combination with carbon and silicon, and silicon present as a silicon carbide, may be the cause of the remarkable hardness of some coke.

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48 Studies of this character will, however, be largely of academic interest unless correlated with studies of the behavior of different types of coke in the blast furnace and in other types of apparatus in which the material is used. Let us choose the blast furnace for consideration here on account of its tremendous industrial importance.

49 There is at present some disagreement among blast-furnace men as to the exact function of the coke in the most efficient and economical reduction of iron ore. The majority probably still accept Grüner's theory of ideal working, viz. (as stated by Richards[1]), "All the carbon burnt in the furnace should first be oxidized at the tuyeres to CO, and all reduction of oxides above the tuyeres should be caused by CO, which thus becomes CO_2." It is well known that the reduction of iron oxide by carbon monoxide is the most efficient from the standpoint of heat economy. Richards, however, has pointed out that the direct reduction of iron oxide by carbon is three times as efficient from the standpoint of carbon required as the indirect reduction, and says:

> The ordinary furnace produces at the tuyeres, in order to get heat enough to melt down the charges, more CO gas than is needed to abstract all the oxygen from the charges; under these conditions it is uneconomical to oxidize any carbon at all above the tuyeres. The exceptional furnace, because of pure ores, small amount of slag, pure fuel, high temperature of blast, or dry blast, gives heat enough at the tuyeres to melt down the charges without producing enough CO gas to reduce all the charges; under these conditions, more or less reduction is effected by solid carbon and with the greatest economy in quantity of carbon required in the furnace.

50 About a year ago H. P. Howland prepared an interesting paper,[2] entitled Calculations With Reference to the Use of Carbon in Modern American Blast Furnaces, calling attention to the fact that many furnaces are actually operating with higher economy of coke than would be calculated from Grüner's theory; in fact, his calculations on the performance of 26 furnaces seem to show that what Richards regarded as the exceptional furnace is the rule rather than the exception in modern practice.

51 Howland's tabulation of data on these 26 furnaces is so interesting and pertinent to the subject that a portion of it is reproduced in Table 4.

52 Note incidentally the performance of the once-despised by-product coke in modern practice. Of the 19 furnaces using less than

[1] Metallurgical and Chemical Calculations, p. 248.

[2] Bull. Am. Inst. Min. Eng., March 1916, p. 627.

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a ton of coke per ton of pig iron, 13 are burning by-product coke and 6 beehive coke.

53 Howland calculates that all the furnaces burning less than 1350 lb. of carbon at the tuyeres are not making enough CO to reduce

TABLE 4 PART OF HOWLAND'S DATA ON AMERICAN BLAST FURNACES

Furnace No.	Pounds coke per ton iron	Tons iron per day	Carbon in coke, per cent	Kind of method of manufacture	Coke operation	Total charged	Gasified in furnace	Gasified at tuyeres	Per cent total carbon	Per cent gasified carbon
1	2,615	301	86.3	BH	Stonega	2,254	2110	1868	82.8	.....
2	2,551	272	84.4	BP	Solvay	2,153	2049	1751	81.4	86.6
3	2,472	482	86.1	BH	Conn.	2,128	1996	1728	81.2	86.8
4	2,247	450	87.1	BH	Conn.	1,957	1846	1605	82.0	87.0
5	2,198	499	86.9	BH	Conn.	1,908	1810	1494	78.7	82.6
6	2,123	541	88.3	BH	Conn.	1,875	1764	1498	79.8	84.9
7	2,115	360	84.3	BP	Solvay	1,782	1683	1427	80.1	84.8
8	1,996	490	86.3	BP	Koppers	1,722	1611	1298	75.4	80.6
9	1,936	376	85.7	BP	Solvay	1,659	1557	1305	78.8	83.7
10	1,905	393	83.7	BP	Solvay	1,690	1575	1252	74.1	79.5
11	1,901	517	85.5	BP	Koppers	1,625	1524	1280	78.8	84.1
12	1,863	504	86.6	BP	Koppers	1,614	1513	1230	76.2	81.3
13	1,780	426	84.9	BP	Koppers	1,511	1414	1124	74.4	79.5
14	1,742	503	84.6	BP	Koppers	1,474	1382	1133	76.9	82.0
15	1,716	542	87.1	BH	Benham	1,494	1396	1194	80.0	87.0
16	1,715	585	84.6	BP	Koppers	1,451	1357	1114	76.6	82.2
17	1,702	543	87.5	BP	Koppers	1,490	1388	1130	75.9	81.5
18	1,699	572	87.0	BP	Koppers	1,479	1387	1155	78.2	83.4
19	1,673	580	88.6	BH	Benham	1,482	1384	1182	79.9	85.0
20	1,658	590	88.3	BH	Benham	1,464	1366	1182	80.8	86.5
21	1,636	442	89.5	BP	Koppers	1,463	1369	1124	76.8	82.1
22	1,635	593	88.5	BH	Benham	1,447	1349	1124	77.7	83.4
23	1,624	592	87.3	BH	Benham	1,417	1317	1118	79.0	85.0
24	1,623	457	89.6	BP	Koppers	1,454	1360	1090	75.0	80.2
25	1,589	608	88.3	BH	Benham	1,403	1307	1100	78.5	84.2
26	1,584	466	89.2	BP	Koppers	1,413	1324	1057	74.8	79.9

NOTE. — BH = Beehive. BP = By-product. Conn. = Connellsville.

all the Fe_2O and hence some of the latter must be reduced directly by carbon. He concludes:

It seems clear, therefore, that in low-coke furnaces one of the most important (if not the most important) functions of the carbon burned at the tuyeres is to produce heat to enable the carrying on of the direct reduction, rather than to produce CO for indirect reduction.

On this basis, it becomes very essential that our carbon shall burn instantaneously to CO in order that the resulting heat may be localized where needed. This should not be a question of seconds, but of a fraction of a second. If our carbon is of such a nature that this burning to CO is a comparatively long process, more of it will be required than of the quick-burning carbon in order to obtain the same concentration of heat at the desired point.

We would, therefore, say that the most desirable thing about a coke is that

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quality in the carbon which will allow of its being instantaneously burned to CO and thus result in the maximum concentration of heat where needed.

FIG. 16 COKE FROM PITTSBURGH COAL, WITH 20 PER CENT POCAHONTAS

FIG. 17 COKE FROM PITTSBURGH COAL, WITH 40 PER CENT POCAHONTAS

54 W. H. Blauvelt, in a discussion of Howland's paper,[1] says:

In studying the combustion of coke in the furnace, it is clear that the production of the maximum quantity of heat is not of the first importance in blast-

[1] Bull. Am. Inst. Min. Eng., October 1916.

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furnace operation, or in the utilization of the fuel charged into the furnace. To my mind, the production of a high thermal head at the tuyeres is of the first

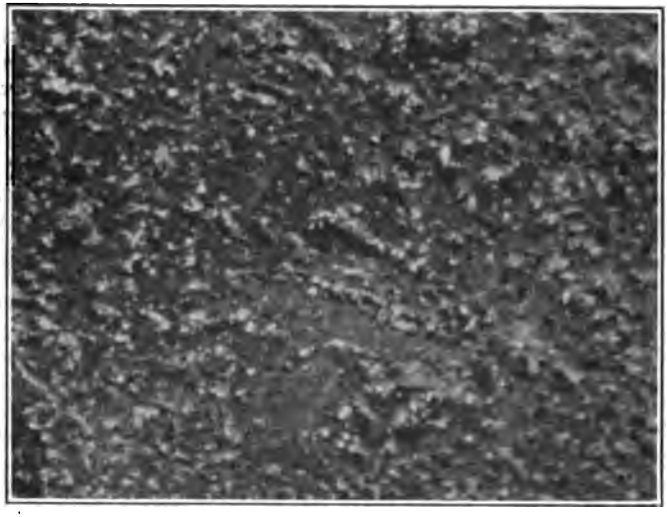

FIG. 18 STANDARD NO. 1 ENLARGED 10 DIAMETERS

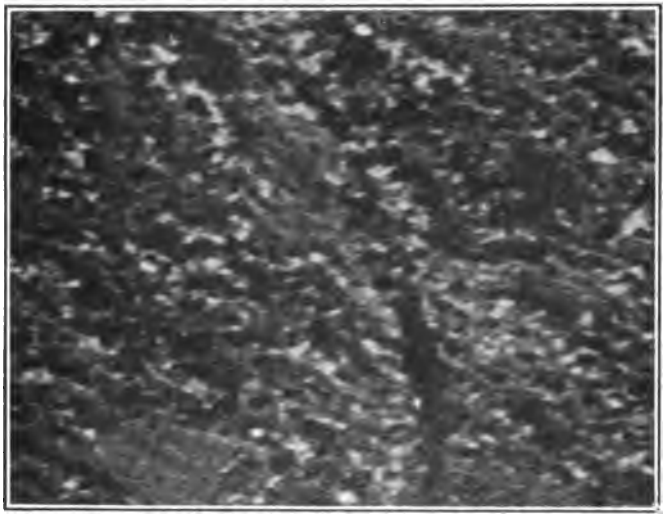

FIG. 19 STANDARD NO. 2 ENLARGED 10 DIAMETERS

importance, and the best coke is that which reaches the tuyeres in proper condition to produce the highest temperature at the tuyeres, and in just sufficient

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quantity to do the amount of work required there under the conditions produced by this maximum temperature. The combustion of a much larger amount of fuel at the tuyeres, under conditions that will fall short of producing the highest possible temperature, cannot produce as good results, either in fuel economy or output. . . . Nothing is more fatal to obtaining the highest temperature than an excess of combustion. In the blast furnace an excess of air dilutes and cools the products of combustion, reducing the maximum thermal head at the tuyeres, and the larger volume carries the high temperature zone too high in the furnace. . . . It will probably be generally admitted that furnace coke should be of nearly uniform size, and many furnace managers are eliminating all coke below ¾ in. and above 4 or 4½ in.; also, that the best coke is that which is sufficiently strong to resist undue abrasion and crumbling by attrition with the stock, and of an open porous structure that will permit the most rapid combustion when it reaches the tuyeres. Many large users agree that the coke should never be overcoked beyond the point of producing a sufficiently strong structure, as overcoking quickly reduces the combustibility.

If Grüner's ideal gives the best furnace operation, we should want a coke that is resistant to the oxygen in the ore but easily combustible at the tuyeres, which is a contradiction of qualities. If my argument is correct, that the furnace man wants the greatest thermal head at the tuyeres rather than the production of the greatest quantity of heat in the furnace as a whole, then he is willing to sacrifice some coke by solution in the oxidising gases in the upper part of the furnace, provided he can obtain a sufficient quantity of coke at the tuyeres, of a quality that will permit rapid combustion with the minimum amount of air, thereby giving him the maximum thermal head.

55 The desirability of the condition which Blauvelt aptly terms *a high thermal head* in the zone of the tuyeres will be readily granted even by those who adhere to Grüner's theory. This condition should be attained even at a sacrifice of some carbon by solution loss ($CO_2 + C = 2CO$), and we are of the opinion that the importance of this solution loss is frequently over-estimated. Most laboratory experiments made to determine the loss undergone by different cokes have been of little value, because they have been mostly made with pulverized samples, so that their original physical condition has been greatly altered.

56 We have lately tested the resistance of a number of cokes to the action of CO_2 at temperatures of 800 and 900 deg., and find the loss of coke pulverized to 40 mesh to be very much greater than the same coke prepared in small test pieces, ⅜ in. by ⅜ in. by 1½ in., so as to retain the original structure.

57 As furnace conditions are better understood, the possibility of the use of coke of a wider instead of a more restricted range of quality will become better recognized, with the express limitation that the supply for each furnace must always be absolutely uniform in quality. This requirement of uniformity cannot be too strongly

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emphasized, and it is almost equally necessary for the proper operation of the coke plant as the blast furnace; but this does not mean that there is one standard grade of coke to which all plants should conform so far as possible. As a matter of fact, the range of cokes that successfully qualify in practical operation is continually being extended, through necessity of one sort or another, with little general realization of the fact. In Figs. 12 to 17 we have already shown the cell structure of some cokes that are giving good results in different American blast furnaces, and the difference is fairly remarkable.

58 However, for each kind of coke there is evidently some limiting size for efficient service, i.e., just large enough to offer such a minimum surface of attack for CO_2 that the loss on this account is negligible, and small enough so that complete combustion may be effected in a minimum of time at the tuyeres. Hardness of body is usually — though possibly not necessarily — proportional to the resistance of a given coke to oxidation by CO_2 or oxygen. The harder grades of coke should be used in smaller sizes — and this is a compensation automatically provided to some extent by the operation of the by-product oven. Similarly, cokes of close cell structure are more resistant to oxidation, but this may be offset to a large extent by softness. The coke of more open cell structure will probably require less rigid attention to sizing than the denser coke. The important thing is to determine the practical limits of these elements of size, hardness, and cell structure. It may be found that a coke of such structure as No. 1 of our scale may be unsuitable, no matter what may be its size or softness; but this ought to be proved by actual test and not taken for granted.

59 These considerations are of the utmost importance and encouragement to the coke-oven man, because, with a reasonable choice of coal, his control over the quality of his coke is almost unlimited, and, even with a very restricted source of supply, the possibilities of conforming to the desired standard by proper oven construction and regulation are still remarkably great. We propose to conclude this paper by showing two or three examples of what can be accomplished in the way of control of this sort.

60 One proposition that frequently presents itself is that of eliminating sponge. Sponge is a characteristic honeycombed mass formed in the center of rich volatile matter. It seems to be caused by an excess of pitchy material moving along with the fused zone in the coking process, and finally accumulating in the center of the oven, where it is eventually gasified, with the production of this light

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porous material. Sometimes this sponge is found in loose, detached masses scattered all over the coke as it lies on the wharf after quench-

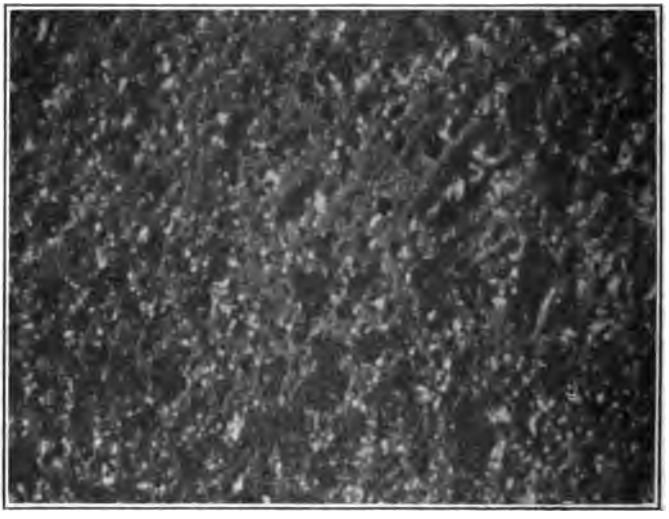

FIG. 20 STANDARD NO. 3 ENLARGED 10 DIAMETERS

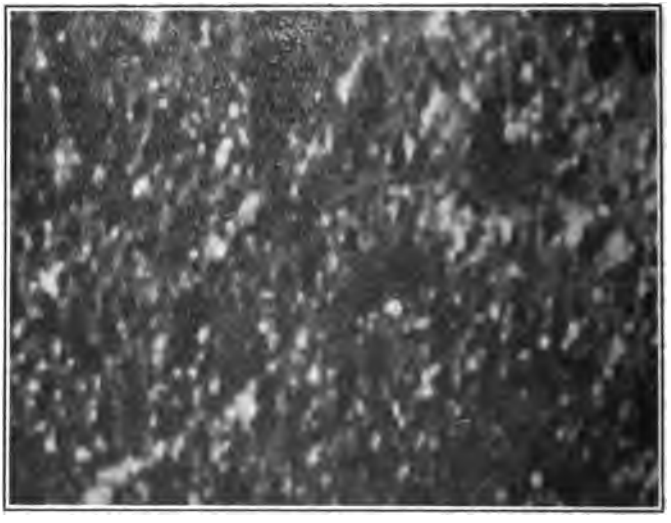

FIG. 21 STANDARD NO. 4 ENLARGED 10 DIAMETERS

ing, or, again, it may be found adhering very closely to the ends of the pieces of coke, and sometimes blending, without any clear line of demarcation, into the body of the coke itself.

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61 Although the amount of this sponge often appears to be very large, it is so bulky that its actual percentage by weight is small. In

FIG. 22 COKE FROM STRAIGHT HIGH-VOLATILE COAL, SHOWING SPONGE

FIG. 23 COKE FROM SAME COAL AS FIG. 22, WITH 20 PER CENT POCAHONTAS

one case where the amount of sponge seemed to be very large it was actually found that it amounted to 1.65 per cent of the total coke.

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Small amounts of sponge probably do no harm, most of the material being soon broken up in the operations of handling the coke, but the

FIG. 24 COKE FROM COLORADO COAL, SHOWING SPONGE

FIG. 25 COKE FROM SAME COAL AS FIG. 24, PROPERLY MADE

presence of the material undoubtedly occasions a certain loss of carbon, and so we usually try to get rid of it. The customary

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remedy — and one that always works — is to mix with the high-volatile coal sufficient low-volatile coal, which has the effect of absorbing the excess of bituminous material and eliminating the conditions of sponge formation. Pocahontas coal is the standard low-volatile coal that is employed by many of our plants. It is to be noted that different coals require considerably different percentages of Poca-

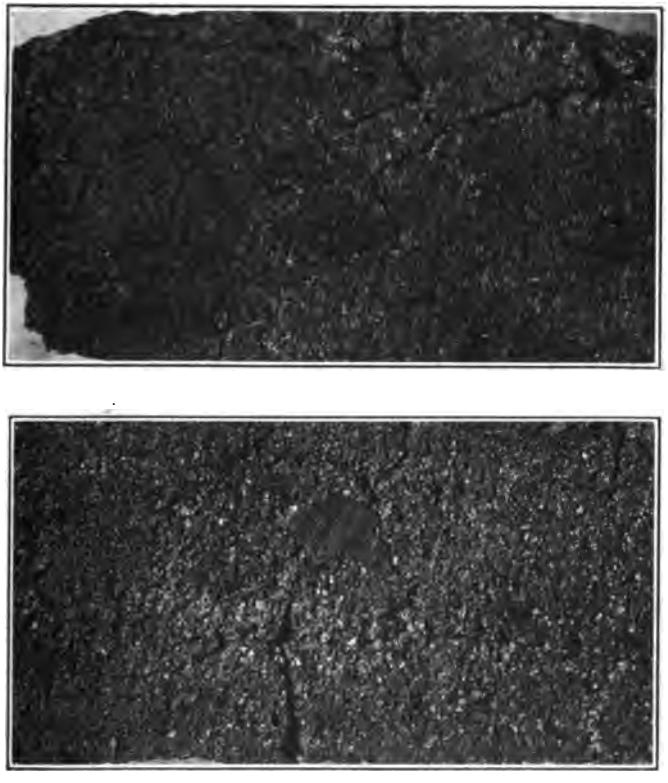

FIG. 26 SAME COAL MIXTURE COKED AT DIFFERENT PLANTS UNDER DIFFERENT CONDITIONS

hontas coal to completely eliminate the sponge. Fig. 22 shows a coke from unmixed high-volatile coal (about 34 per cent volatile matter). A large amount of sponge is readily apparent. Fig. 23 shows the coal from a mixture containing 80 per cent of this same coal with 20 per cent of Pocahontas. The sponge is entirely eliminated and the structure of the coke improved.

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62 Frequently it is too expensive a proposition to buy low-volatile coal for the sake of eliminating a little sponge, and sometimes the low-volatile coal may be altogether inaccessible for practical purposes. This does not, however, leave us at the end of our resources. By proper methods of control, sponge may be eliminated from a wide variety of coals that produce it under ordinary conditions. If the oven is correctly designed and proportioned, and the temperature and coking time carefully regulated, very satisfactory results may be obtained without the necessity of making a special coal mixture. Fig. 24 shows the coke from one coal which was made in a type of oven unsuited to it, and coked at unfavorable temperatures. Fig. 25 shows coke made from the same coal under proper conditions. The sponge has been entirely eliminated.

63 Occasionally one of the most difficult problems to be overcome is that of too great density of cell structure. Here, again, we can approach the problem in two ways: one, by mixing in one or more other coals that have a tendency to the production of a more open cell structure, and the other way by suitable preliminary preparation of the coal, careful heat control, and special design of the oven. Fig. 26 shows coke made from the same coal mixture coked at different plants under different conditions. The dense coke shown in the lower part of the figure was greatly improved upon when the nature of the coal was better understood, and the excellent product shown in the upper part of the figure was then made when the coal was treated in the right kind of ovens and under proper conditions.

64 To insure the best results a special study must be made of each kind of coal it is proposed to use, and it would be well, in all cases where a new plant is contemplated, to make this study previous to designing the plant, because the results may suggest some necessary changes in design that would not otherwise be foreseen.

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No. 1620

COMBINED STRESSES

By A. Lewis Jenkins, Cincinnati, O.
Member of the Society

The author discusses the six possible hypotheses upon which a formula for combined normal and shearing stresses may be based, namely, the maximum apparent and the maximum true or equivalent stresses in tension, compression and shear. His conclusion is that the equivalent stresses are a refinement over the apparent stresses, and he finds that both theoretical and experimental results show them to be the more accurate.

Equivalent-stress formulæ for tensile, compressive and shear stresses are given in the paper, and their uses are indicated (1) *with respect to the value found for the ratio of the unit tensile and shearing stresses at the yield point, and* (2) *with respect to the nature of the failure of the material.*

The design of shafts subjected to bending and twisting is dealt with at length and formulæ are recommended for use with hard or brittle materials, such as cast iron or hard steel, and with soft or ductile materials, such as very mild steels.

IN the past few years much has been written regarding the applications of the formulæ for combined stresses. The discussions consist of theoretical and experimental analyses of the stress relations resulting from complex loadings which produce more than one kind of simple stress, such as combined shear and tension; and most of these are endeavors to prove that the designer should base his calculations on the maximum existing shear stress regardless of the relative strengths of the materials in tension, compression and shear.

2 This popularity and stimulated interest in the subject of combined stresses was induced by Guest, who in 1900 published the results of his tests on the strengths of soft steel, copper and brass tubing when subjected to bending and twisting. The main conclusion drawn from the results of these experiments was that they were in accordance with the previously established fact that soft steel and most ductile materials are weaker in shear than in tension. Recently several writers have extensively advocated the

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use of the maximum-shear-stress hypothesis until they have reached the limit of having suggested its application in the design of cast-iron members! One of the most recent handbooks for designers gives only Guest's formula for the design of shafting subjected to combined bending and twisting, without mentioning the fact that it is absurd to use it for anything but a soft, ductile material.

3 There are six possible hypotheses upon which a formula for combined normal and shearing stresses may be based, namely, the maximum apparent and the maximum true or equivalent stresses in tension, compression and shear. Of these only the maximum apparent stresses in tension and shear and the equivalent tensile stress have been generally proposed for the design of shafts. Guest's formula is evidently not based on the apparent maximum shear stress as some writers have assumed.

APPARENT AND EQUIVALENT STRESSES DUE TO LOADS THAT PRODUCE SIMPLE TENSION AND COMPRESSION DIRECTLY

4 *Apparent Stresses in Normal and Oblique Planes.* The bar shown in Fig. 1 is subjected to a compressive load W, and the simple compressive unit stress on the section EB is $C = W/A$, where A is the area of the cross-section through EB.

5 The area of the cross-section through DF, inclined at an angle G with EB, is $A/\cos G$; and the force normal to the plane DF is $W \cos G$; hence the apparent compressive unit stress acting normal to DF is

$$C' = \frac{W \cos G}{A/\cos G} = \frac{W \cos^2 G}{A} = C \cos^2 G$$

6 The component of W acting parallel to DF is $W \sin G$; hence the apparent tangential or shear unit stress along DF is

$$S' = \frac{W \sin G}{A/\cos G} = \frac{W \sin G \times \cos G}{A} = \frac{C \sin 2G}{2}$$

7 The value of S' is a maximum when $G = 45$ deg., which means that the maximum apparent shear stress is along the plane making 45 deg. with the direction of the load and is equal to

$$S' = \frac{C}{2} = \frac{W}{2A} \quad \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

This indicates that the shear stress in a cast-iron cube is roughly equal to half the compressive stress when failure occurs.

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8 The bar shown in Fig. 2 is subjected to two compressive loads W_1 and W_2 acting at right angles. Denoting the simple compressive unit stresses by C_1 and C_2 respectively, the apparent compressive unit stress on the plane DF is equal to

$$C' = C_1 \cos^2 G + C_2 \sin^2 G \quad \ldots\ldots\ldots\ldots\ldots\ldots [2]$$

and the apparent unit shear stress on DF is

$$S' = \frac{C_1}{2} \sin 2G - \frac{C_2}{2} \sin 2G$$

which is a maximum when $G = 45$ deg. and equal to

$$S' = \tfrac{1}{2}(C_1 - C_2) \quad \ldots\ldots\ldots\ldots\ldots\ldots [3]$$

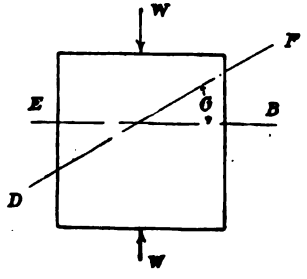

FIG. 1 BAR SUBJECTED TO COMPRESSIVE LOAD

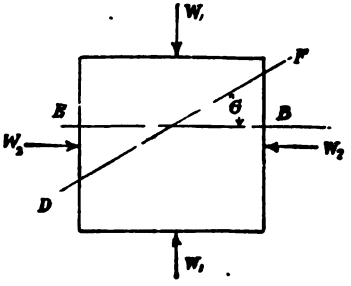

FIG. 2 BAR SUBJECTED TO TWO COMPRESSIVE LOADS

9 If W_1 and W_2 were reversed, they would produce tension instead of compression, and the apparent tensile unit stress on DF would be

$$T' = T_1 \cos^2 G + T_2 \sin^2 G$$

where $T_1 = W_1/A_1$ and $T_2 = W_2/A_2$. The maximum apparent shearing unit stress is a maximum when $G = 45$ deg. and is equal to

$$S' = \tfrac{1}{2}(T_1 - T_2)$$

10 If W_1 produced direct compression and W_2 direct tension, the apparent unit stresses would be

$$C' = C_1 \cos^2 G - T_2 \sin^2 G$$
$$T' = T_2 \sin^2 G - C_1 \cos^2 G$$

and the maximum apparent shearing stress is

$$S' = \tfrac{1}{2}(C_1 + T_2)$$

11 It is seen from Equation [2] that the greatest apparent compressive unit stress for the loading shown in Fig. 2 is either

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$C_1 = W_1/A_1$ or $C_2 = W_2/A_2$, depending upon the relative values of the loads and respective areas, the compressive stress normal to W_1 being independent of the load W_2 or the unit stress C_2.

12 *Equivalent Stresses in Normal and Oblique Planes.* The above method of determining the effect of combined stresses employs the ordinary methods of statics, and the results are known as apparent stresses. The method is based on the conception that unit stress is an internal resisting force acting on a unit area, and is found by dividing the load by the area.

13 A better conception of stress assumes that it is that property of a material which resists deformation of strain, and its intensity is measured by the product Es, where E is the modulus of elasticity and s the unit strain or deformation produced in a unit of length.

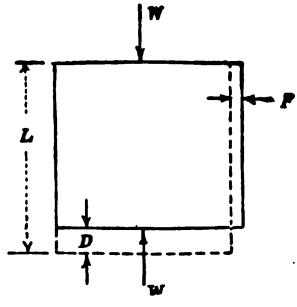

FIG. 3 DEFORMATION OF LOADED BAR

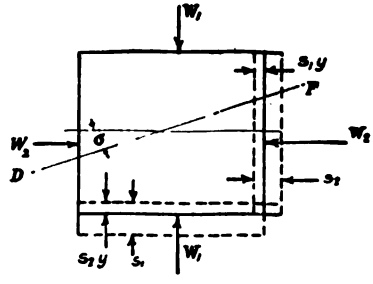

FIG. 4 DIRECT COMPRESSIVE UNIT STRAIN ON BAR

14 In Fig. 3 the load W deforms the bar of unit area an amount equal to D and the unit deformation in the direction of W is $s = D/L$, where L is the length of the bar, and the unit compressive stress is $C = Es$.

15 Although there is a slight decrease in the volume in this case, due to the load W, the lateral dimension, which is equal to unity, is increased an amount equal to F. The ratio $F/(D/L) = F/s = y$ for a unit block is a constant for a given material and is known as Poisson's ratio of lateral contraction. For any size block having a lateral dimension in the direction of F equal to L', then $y = (F/L') \div (D/L)$.

16 In Fig. 4, W_1 produces a direct compressive unit strain in its direction equal to $s_1 = C_1/E$ and a lateral unit strain (extension) equal to $s_1 y$.

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17 The total unit strain in the direction of W_1 is

$$s_1 - s_2 y = \frac{C_1}{E} - \frac{C_2 y}{E}$$

18 The equivalent stress, or the single simple stress that will produce an equivalent strain in the direction of W_1 equal to that actually produced in that direction by the combined action of W_1 and W_2, is C_{e_1}. Hence

$$\frac{C_{e_1}}{E} = \frac{C_1}{E} - \frac{C_2 y}{E}$$

and $C_{e_1} = C_1 - C_2 y$.

19 Similarly, the equivalent stress in the direction of W_2 is

$$C_{e_2} = C_2 - C_1 y.$$

20 The equivalent compressive stress on the section DF is

$$C_e = C_{e_1} \cos^2 G + C_{e_2} \sin^2 G$$

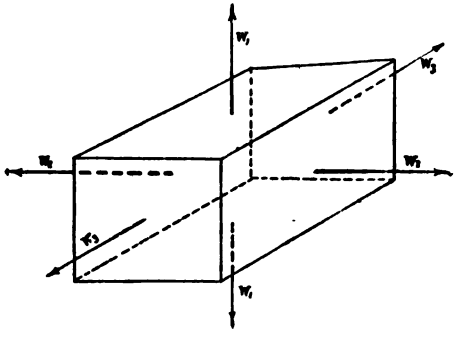

FIG. 5 LOADS IN THREE DIRECTIONS

and the maximum equivalent shear stress is

$$S_e = \tfrac{1}{2}(C_{e_1} - C_{e_2}) = \tfrac{1}{2}(C_{e_1} - C_{e_2} y - C_2 + C_1 y)$$
$$= \frac{1+y}{2}(C_1 - C_2) \ldots\ldots\ldots\ldots\ldots\ldots [4]$$

21 In general, the equivalent normal stresses (compression and tension) produced by simple compressive and tensile stresses acting in three directions perpendicular to one another, as shown in Fig. 5, are, when all are tension,

$$T_{e_1} = T_1 - T_2 y - T_3 y$$
$$T_{e_2} = T_2 - T_1 y - T_3 y$$
$$T_{e_3} = T_3 - T_1 y - T_2 y$$

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If any of the stresses should be compression instead of tension, its sign in the above equations should be changed.

22 The equivalent shearing stresses are:

$$S_e = \tfrac{1}{2}(T_{e_1} - T_{e_2}) \text{ in the plane of } S_1 \text{ and } S_2$$
$$S_e = \tfrac{1}{2}(T_{e_2} - T_{e_3}) \text{ in the plane of } S_2 \text{ and } S_3, \text{ etc.}$$

MAXIMUM APPARENT AND EQUIVALENT STRESSES DUE TO COMBINED NORMAL AND SHEAR STRESSES

23 In machine construction many parts are required to resist both a single normal stress (tension or compression) and a simple shear stress. Cases where a machine element is subjected to more than one normal stress, together with one or more shear stresses, are quite rare; but there are many examples of a single normal stress being combined with a single shear stress, as in shafts being subjected to bending and twisting, propeller shafts, webs of beams, girders and machine frames, lathe beds, planer and boring-mill rails, spindles of milling machines, drilling machines and saws, bolts, screws for transmitting power, and numerous other machine parts.

24 Let the rectangle in Fig. 6 represent a small elementary area subjected to both a simple tensile stress T and a simple shear stress S, such as exists on the tension side of a shaft subjected to bending and twisting or in the web of a beam subjected to bending. On the compression side of a shaft or beam the normal stress is compression, or negative, and is denoted by C as shown in Fig. 7.

25 The normal stresses T and C may be produced by loads causing tension, compression or by any of their combinations, and the shear stress S may be produced by torsion or any other shearing action, such as vertical and horizontal shear in beams.

26 There are two ways in which the combined effect of these simple stresses may be expressed, namely,

a By employing the ordinary methods of statics, in which case the results are known as apparent stresses

b By applying the elastic theory, which states that the stress depends entirely upon the deformation or strain in the body. The results of this method, which is merely a refinement of the other, are called equivalent stresses.

The derivation of the formulæ for finding these stresses may be found in most textbooks on the strength of materials.

27 *Maximum Apparent Normal Stresses.* By resolving the

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stresses T, C and S perpendicular and parallel to any line such as AB in Fig. 6, the apparent shear stress along AB and the apparent compressive stress perpendicular to it may be found. Similarly, the tensile stress on FD may be found. When $\tan 2G = -2S/T$, the normal stresses are a maximum, which gives for the maximum apparent tensile stress

$$T' = \frac{T}{2} + \frac{1}{2}\sqrt{4S^2 + T^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [5]$$

and for the maximum apparent compressive stress acting at right angles to it

$$C' = \frac{T}{2} - \frac{1}{2}\sqrt{4S^2 + T^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [6]$$

Similarly, in Fig. 7 the maximum apparent tensile stress is

$$T' = \frac{C}{2} - \frac{1}{2}\sqrt{4S^2 + C^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [7]$$

and the maximum apparent compressive stress is

$$C' = \frac{C}{2} + \frac{1}{2}\sqrt{4S^2 + C^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [8]$$

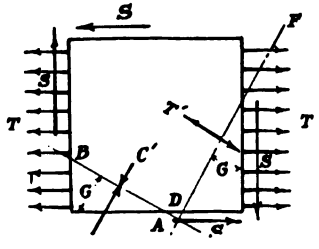

FIG. 6 SMALL ELEMENTARY AREA IN SIMPLE TENSION AND SHEAR

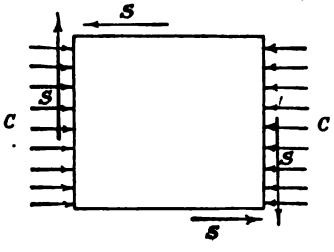

FIG. 7 NORMAL STRESS ON COMPRESSIVE SIDE

28 From these equations it is seen that if a body is subjected to both a simple tension and a simple shear stress, the maximum apparent tensile stress is greater than the maximum apparent compressive stress by an amount equal to

$$T' - C' = \sqrt{4S^2 + T^2}$$

29 In the case of a circular shaft subjected to bending and twisting, the stresses due to bending are T on the tension side and C on the compression side, and since these are numerically equal, the values of T' and C' are also equal.

30 Rankine held that the yielding of a material subjected to combined stresses depends entirely upon the maximum apparent

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normal stress, and is independent of the apparent shear and other stresses which may act at right angles to it. He also made no distinction as to the relative strengths of material in simple tension, compression and shear.

31 *Maximum Apparent Shear Stress.* The apparent shear stress acting along AB in Fig. 6 becomes a maximum when $\cot G = 2\,S/T$ and is equal to

$$S' = \tfrac{1}{2}\sqrt{4\,S^2 + T^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [9]$$

and for Fig. 7

$$S' = -\tfrac{1}{2}\sqrt{4\,S^2 + C^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [10]$$

32 These formulæ have recently become popular on account of some writers having suggested their use in preference to any others, and by so doing they have made the same claims for them as Rankine made for the maximum-normal-stress formulæ, and again the relative strength of the material has been neglected.

33 *Maximum Equivalent Normal Stresses.* Any point on the surface of an area subjected to the simple stresses T and S is acted upon by an apparent tensile and an apparent compressive stress having directions at right angles to each other. In the planes of maximum stress these stresses become T' and C' and they produce a deformation or strain equal to

$$\frac{T'}{E} - \frac{C'y}{E}$$

The equivalent stress, namely, that single tensile stress which would produce a deformation equal to that actually produced by T' and C', is

$$T_e = T' - C'y$$

and the equivalent compressive stress is

$$C_e = C' - T'y$$

By substituting the values of T' and C',

$$T_e = \frac{1-y}{2}T + \frac{1+y}{2}\sqrt{4\,S^2 + T^2} \quad \ldots\ldots\ldots\ldots [11]$$

and

$$C_e = \frac{1-y}{2}T - \frac{1+y}{2}\sqrt{4\,S^2 + T^2} \quad \ldots\ldots\ldots\ldots [12]$$

34 In Fig. 7 the equivalent tensile stress is

$$T_e = \frac{1-y}{2}C - \frac{1+y}{2}\sqrt{4\,S^2 + C^2} \quad \ldots\ldots\ldots\ldots [13]$$

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and the equivalent compressive stress is

$$C_e = \frac{1-y}{2} C + \frac{1+y}{2} \sqrt{4S^2 + C^2} \quad \text{[14]}$$

35 It should be noted that according to Equation [11], $T_e = (1+y)S$ when $T = 0$; and $T_e = T$ when $S = 0$.

36 The theory that these equations should be applied to problems in combined stresses is due to Saint Venant, and is based on the assumption that the yield point of a material does not depend upon the apparent stress or stresses in any given direction, but upon the deformation or strain. It is sometimes known as the "maximum-strain theory." This theory also neglects the relative strengths of the material.

37 *Equivalent Shear Stress.* The equivalent shear stress is

$$S_e = \tfrac{1}{2}(T_e - C_e)$$

and by substituting for the case shown in Fig. 6,

$$S_e = \frac{1+y}{2} \sqrt{4S^2 + T^2} \quad \text{[15]}$$

and for Fig. 7,

$$S_e = -\frac{1+y}{2} \sqrt{4S^2 + C^2} \quad \text{[16]}$$

38 In Equation [15] it should be noted that $S_e = (1+y)S$ when $T = 0$; and $S_e = \frac{(1+y)}{2} T$ when $S = 0$.

39 The quantity $1+y$ is the ratio of the modulus of elasticity in tension to the modulus of elasticity in shear (modulus of rigidity). This indicates that the true stress in a circular shaft subjected to a torsional moment M_t is

$$S_e = \frac{5.1\, M_t (1+y)}{D^3}$$

and the true shear produced by a direct or purely tension or compression load is

$$S_e = \frac{(1+y)}{2} T \text{ instead of } \frac{1}{2} T, \text{ and}$$

$$C_e = \frac{(1+y)\, C}{2} \text{ instead of } \frac{1}{2} C.$$

40 Although these formulæ are given in Merriman's Mechanics of Materials in the form $S_e = \frac{(T_e - C_e)}{2}$, they have not been mentioned in the numerous discussions on combined stresses occurring in engineering periodicals.

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RELATIVE STRENGTHS OF MATERIALS

41 Hard or brittle steels and cast iron fail in tension when subjected to torsional load or a tension load, and in shear when subjected to compression. Soft steels and other ductile materials fail in shear when subjected to either a tension or compression load or a torsional moment.

42 A hard-steel or cast-iron beam of T cross-section will fail in tension even though the flange is on the tension side. It is practically impossible to design a cast-iron beam that will fail on the compression side, and if the facilities for testing the strengths of materials were limited to a bending test, not even a conception of the compression resistance of cast iron could be determined. Neither can the shearing strength of a rectangular or a round bar made of brittle steel be determined from a bending test, for the simple reason that the tensile stress reaches the ultimate strength of the material before either the compressive or shear stresses become ultimate.

43 A torsion test of a round bar is extensively used in determining the shearing strengths of materials because pure torsion produces a shear stress that is greater than the normal stresses. The apparent normal and equivalent stresses produced are at least equal to the shear stress, and if the material is stronger in shear than in tension it will fail in tension along a helical surface making an angle of about 45 deg. with the surface of the bar. Such a test is by no means a measure of the shearing strength of a brittle material such as cast iron.

44 When a highly finished soft-steel bar is subjected to tension, a series of lines inclined to the axis at about 45 deg. are readily noticeable after the elastic limit has been reached. These are known as "Lüder's lines," and are in the direction of the maximum shear stress. They indicate that the elastic shearing resistance and not the elastic tensile stress determines the yield point. Soft-steel bars actually fail in shear with a cup-shaped fracture that is somewhat modified by the flow of the metal during contraction.

45 It is known that brittle materials do not suffer an appreciable lateral contraction before failing in tension. They are stronger in shear than in tension, and the yield point of a hardened-steel bar almost coincides with the ultimate strength, it being elastic under almost any load within its ultimate strength. These facts suggest that the yield point and elastic limit might be wholly de-

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pendent upon the shear and not upon the tension- or compression-resisting properties of the material. In the light of the present knowledge of the effect of hardening steels, it is entirely possible that the actual ultimate tensile stress is not increased by hardening and the apparent increase in tensile strength is caused by the increased shearing resistance due to the treatment.

46 In view of these facts, it seems quite probable that the tension test of a soft-steel bar does not reveal its true tensile strength, yield point or elastic limit with any greater degree of accuracy than a torsion test reveals the shearing strength of hard steel or cast iron. It would be very interesting to know the tensile strength of a bar loaded in such a way as to eliminate the shearing stresses and thereby forcing its failure to occur in tension.

47 The term *compressive strength* is merely used to denote the unit compressive stress in a body subjected to a compressive load when the shearing stresses and friction can no longer resist rupture.

48 It is easy to see that a bar may be ruptured in tension by the fractured surfaces separating normally or in shear by the fractured surfaces sliding upon each other, producing tangential separation; but in the case of a short bar of metal or stone subjected to compression, the direct effect of the load is to press the material together instead of producing separation.

49 Very soft materials, when subjected to compression, flow laterally and do not separate; whereas brittle materials fail in shear before they will flow, and some steels develop cracks parallel to the direction of the load after the material has suffered considerable lateral extension, showing that the separation is caused by tension. It is difficult to acquire an abstract conception of ultimate compressive strength, and no means are available by which even the elastic compressive strength may be shown to be dependent upon any property other than the elastic strength in shear.

SELECTION OF FORMULA FOR A GIVEN MATERIAL AND LOADING

50 A body subjected to a complex loading will fail when the stress in any direction at any point reaches the ultimate resistance of the material in that direction at that point.

51 Conceive of a chain consisting of three or more elements of special design — one link so designed that the maximum stress is tension, another in which the compressive stress is much higher than the tension or shear, and the third element having its mini-

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mum resistance in shear. The links are so proportioned that a load on the chain will produce a tension, compression and shear stress in the respective links that is numerically the same for all. How would the chain fail? If made of cast iron it would fail in tension, if of glass it would fail in compression, and if of soft steel it would fail in shear. It is obviously absurd to say that such a chain constructed of hard steel or cast iron would fail in shear; yet that is in accord with the idea that some discussions on combined stresses were intended to convey.

52 According to Hancock, the numerical values of the stress at the yield point and at the elastic limit are practically equal. It has also been observed that a material usually fails ultimately in the same manner in which it first yields; hence the yield points or elastic strengths of a material may be used as a criterion of its relative ultimate strengths.

53 Let Q = yield point in shear
P = yield point in tension
F_s = factor of safety in shear = Q/S_s
F_t = factor of safety in tension = P/T_s

In order to have equal factors of safety against yielding in tension and shear,

$$F_t = F_s \text{ and } \frac{F_t}{F_s} = 1$$

Substituting the values given above for F_t and F_s,

$$\frac{P/T_s}{Q/S_s} = 1$$

whence

$$\frac{P}{Q} = \frac{T_s}{S_s} = \frac{(1-y)\,T/S}{(1+y)\,\sqrt{4+T^2/S^2}} + 1 \quad \ldots\ldots\ldots\ldots [17]$$

54 If the right-hand side of this equation is greater than the left the factor of safety in tension is less than the factor of safety in shear and yielding will occur first in tension; which shows that the equivalent-normal-stress formula should be used. If the left-hand member is the greater, yielding will occur first in shear, showing that the formula for equivalent shear stress should be used.

55 If the value for Q is obtained by a torsion test it is more accurate to use

$$\frac{P}{Q} = \frac{T_s}{S_s} = \frac{(1-y)\,T/S}{\sqrt{4+T^2/S^2}} + 1 + y \quad \ldots\ldots\ldots\ldots [18]$$

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56 These formulæ are for determining whether a body made of a given material and subjected to a given shear and a given tensile stress is weaker in shear than in tension and enable the designer to select the proper formula. Similar formulæ may be written for compression and shear or compression and tension.

FORMULÆ FOR THE DESIGN OF SHAFTS SUBJECTED TO BENDING AND TWISTING

57 Let M_b = external bending moment
M_t = external twisting moment
M_{be} = equivalent bending moment which would produce the same normal stress as M_b and M_t
M_{te} = the equivalent twisting moment that would produce the same shear stress as M_b and M_t
I = rectangular moment of inertia
J = polar moment of inertia
c = distance from the neutral axis to the extreme fiber or radius of a round shaft
Z_t = rectangular modulus of section, I/c; for round section = $D^3/10.2$
Z_p = polar modulus of section, $J/c = 2\,I/c = D^3/5.1$ for round section
D = diameter of shaft
P = unit tensile stress at yield point
Q = unit shearing stress at yield point
T = working stress in tension
S = working stress in shear.

Then

$$M_b = TI/c \quad \text{and} \quad M_t = SJ/c$$

58 *Maximum-Normal-Stress Theory.* According to the maximum-normal-stress theory the stress producing yielding is

$$T' = \frac{T}{2} + \frac{1}{2}\sqrt{4S^2 + T^2} \qquad [19]$$

By multiplying this equation through by J/c and remembering that $J/c = 2\,I/c$, it becomes

$$T'I/c = TI/2\,c + \tfrac{1}{2}\sqrt{S^2J^2/c^2 + T^2I^2/c^2}$$

By substitution, the equivalent bending moment is

$$M_{be} = \tfrac{1}{2}\,(M_b + \sqrt{M_b^2 + M_t^2}) \qquad [20]$$

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and consequently the stress is

$$T' = \frac{5.1}{D^3}\left(M_b + \sqrt{M_b^2 + M_t^2}\right) \quad \ldots\ldots\ldots\ldots\ldots [21]$$

The form frequently given in textbooks is due to Rankine, who wrote it in terms of the equivalent twisting moment, namely,

$$M_{te} = M_b + \sqrt{M_b^2 + M_t^2} \quad \ldots\ldots\ldots\ldots\ldots [22]$$

from which the shearing stress is

$$S' = \frac{5.1}{D^3}\left(M_b + \sqrt{M_b^2 + M_t^2}\right) \quad \ldots\ldots\ldots\ldots\ldots [23]$$

which is the same value as given for the tensile stress above. This is due to the substitution of M_{te} for $T'J/c$ in the derivation of the latter formula. If the tensile stress at the yield point due to bending is the same as shearing stress at the yield point due to torsion, T' might be substituted for S'; but as a matter of fact, the ratio P/Q is not unity. The requirement for equal factors of safety in shear and in tension was found to be $T' = PS'/Q$. Hence, Rankine's equation should be written

$$M_{te} = \frac{Q}{P}\left(M_b + \sqrt{M_b^2 + M_t^2}\right) \quad \ldots\ldots\ldots\ldots\ldots [24]$$

for the general case.

59 *Maximum-Strain or Maximum-Equivalent-Normal-Stress Theory.* According to Saint Venant's theory the stress producing yielding is

$$T_e = \frac{(1-y)}{2}T + \frac{(1+y)}{2}\sqrt{4S^2 + T^2} \quad \ldots\ldots\ldots\ldots [25]$$

By the same method used in the preceding case it is found that

$$M_{be} = \frac{(1-y)}{2}M_b + \frac{(1+y)}{2}\sqrt{M_b^2 + M_t^2} \quad \ldots\ldots\ldots\ldots [26]$$

and

$$M_{te} = \frac{Q}{P}\left[(1-y)M_b + (1+y)\sqrt{M_b^2 + M_t^2}\right] \quad \ldots\ldots\ldots [27]$$

60 The formula used by French engineers is

$$M_{be} = 0.375\,M_b + 0.625\sqrt{M_b^2 + M_t^2} \quad \ldots\ldots\ldots\ldots [28]$$

and was derived by Grashof, who used 0.25 for the value of y.

61 The formula due to Bach and much used in Germany is

$$M_{be} = 0.35\,M_b + 0.65\sqrt{M_b^2 + M_t^2} \quad \ldots\ldots\ldots\ldots [29]$$

the value of y being taken equal to 0.3.

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62 *Maximum-Apparent-Shear-Stress Theory.* It has been shown that the maximum apparent shear stress is

$$S' = \tfrac{1}{2}\sqrt{4S^2 + T^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [30]$$

By multiplying through by J/c and substituting, it is found that

$$M_{te} = \sqrt{M_b^2 + M_t^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [31]$$

and

$$M_{be} = \frac{P}{2Q}\sqrt{M_b^2 + M_t^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [32]$$

63 *Equivalent-Shear-Stress Theory.* From the equation for equivalent shear stress

$$S_e = \frac{(1+y)}{2}\sqrt{4S^2 + T^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [33]$$

The equivalent twisting and bending moments are

$$M_{te} = (1+y)\sqrt{M_b^2 + M_t^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [34]$$

and

$$M_{be} = \frac{P}{2Q}(1+y)\sqrt{M_b^2 + M_t^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [35]$$

64 *Maximum Compressive Strength.* The fact that practically all materials used in machine construction are equally as strong or stronger in compression than in shear or tension eliminates the compressive strength as a criterion in design. Glass has the distinction of having a greater resistance in tension than in compression, and if its physical properties were definitely known it is quite probable that the maximum-compressive-stress theory would be found applicable.

65 *Guest's Formula.* The formula deduced by Guest from his experiments is written

$$M_{be} = \sqrt{M_b^2 + M_t^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [36]$$

whereas the maximum apparent shear stress gives

$$M_{te} = \sqrt{M_b^2 + M_t^2}$$

In order to determine the diameter of shaft the former is equated with $TD^3/10.2$ and the latter with $SD^3/5.1$, which causes Guest's formula to give a stress twice that of the maximum-apparent-shear-stress formula.

66 The expression given by Guest could be obtained from Equation [32] if $P/Q = 2$, or from Equation [35] when

$$P\frac{(1+y)}{2Q} = 1$$

By assuming $y = 0.3$ this expression reduces to $P/Q = 1.54$.

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67 Guest did not give the values of P/Q and y for the materials used in his experiments. The values of P/Q given by Hancock [1] are as follows:

Material	P	Q	P/Q
Steel tubing	21,000	10,500	2.000
Nickel steel	76,500	38,000	2.013
Mild carbon steel	47,000	30,500	1.546
Steel (Scoble)	64,600	29,170	2.214
Carbon steel	55,500	24,400	1.454
Rivet steel	38,900	23,400	1.662
Nickel steel	56,000	35,000	1.555
Steel tubing	17,000	11,500	1.478
Steel tubing	28,000	16,000	1.750
Steel tubing	20,000	12,000	1.666

68 It is seen from the results in this table that the value of $P/Q = 1.54$ corresponds to that given for mild carbon steel; and the values for steel tubing, the material used by Guest, vary from 1.47 to 2.00. These results apparently favor the two shearing-stress theories about equally well; but by accepting the elastic theory it is preferable to assume that the value 1.54 is the proper one to use, which means that the equivalent-shear-stress theory is the more accurate of the two and should be used for soft or ductile materials. There is nothing in Guest's results to show which of these theories he used. His formula is empirical and the data on the elastic limits and ratios of lateral contraction are lacking.

69 *Selection of Formula.* For the design of shafts made of hard or brittle material, such as cast iron or hard steel, the Grashof formula

$$M_{be} = \frac{3\,M_b}{8} + \frac{5}{8}\sqrt{M_b^2 + M_t^2}$$

should be used.

70 For the design of shafts made of soft or ductile materials, such as very mild steels, the equivalent-shear-stress formula

$$M_{te} = (1 + y)\sqrt{M_b^2 + M_t^2} = 1.3\sqrt{M_b^2 + M_t^2}$$

should be used.

71 When the equation

$$\frac{P}{Q} = \frac{(1 - y)\,M_b}{(1 + y)\sqrt{M_b^2 + M_t^2}} + 1$$

[1] Proceedings A.S.T.M., vol. viii, 1908.

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is satisfied, both of the above equations give the same result and either may be used. When the right-hand side of the equation is the greater, use the equivalent-normal-stress formula, and when less use the equivalent-shear-stress formula.

CONCLUSION

72 The equivalent stresses are a refinement over the apparent stresses, and both theoretical and experimental results show that the former are the more accurate. The equivalent-stress formulæ are written as follows:

Equivalent tensile stresses are

$$T_e = \frac{(1-y)}{2} T + \frac{(1+y)}{2} \sqrt{4S^2 + T^2}$$

$$T_e = \frac{(1-y)}{2} C - \frac{(1+y)}{2} \sqrt{4S^2 + C^2}$$

Equivalent compressive stresses are

$$C_e = \frac{(1-y)}{2} C + \frac{(1+y)}{2} \sqrt{4S^2 + C^2}$$

$$C_e = \frac{(1-y)}{2} T - \frac{(1+y)}{2} \sqrt{4S^2 + T^2}$$

Equivalent shear stresses are

$$S_e = \frac{(1+y)}{2} \sqrt{4S^2 + T^2}$$

$$S_e = \frac{(1+y)}{2} \sqrt{4S^2 + C^2}$$

73 The tensile-stress formulæ should be used when P/Q is less, and the shear-stress formulæ should be used when P/Q is greater, than

$$\frac{(1-y)\,T}{(1+y)\sqrt{4S^2 + T^2}} + 1$$

74 If the material fails in torsion with a helical-shaped fracture, the equivalent-normal-stress formula should be used, and if in torsion it fails in a plane perpendicular to the axis, the equivalent-shear-stress formula should be used.

75 If a material fails in tension with a decided cup-shaped fracture, the equivalent-shear-stress formula should be used; whereas failure perpendicular to the axis of the tension specimen indicates that the equivalent-normal-stress formula is preferable.

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DISCUSSION

FRANK E. SANBORN (written). In Par. 58 the author gives Equation [20] and from it Equation [21]:

$$T' = \frac{5.1}{D^3}\left(M_b + \sqrt{M_b^2 + M_t^2}\right)$$

This equation, written with the external moment equal to the internal moments and with no cancellation of numerical values, is of the form

$$\frac{T'\pi D^3}{32} = \tfrac{1}{2}\left(M_b + \sqrt{M_b^2 + M_t^2}\right) \ldots\ldots\ldots\ldots [A]$$

This value T' is a *tension* value and has been derived as such from Fig. 6. Also Equation [23] may be rewritten in the form

$$\frac{S'\pi D^3}{16} = M_b + \sqrt{M_b^2 + M_t^2} \ldots\ldots\ldots\ldots [B]$$

Now the only numerical difference between Equations [A] and [B] is in the factor 2 in the denominator. The results are bound to be the same as long as the numerical value of S' is the same as T'. But putting S' to represent a *shear* value is merely an artifice, as the proper value is *tension*.

The first part of Equation [A] is in the ordinary form of the resistance to bending of a round-sectioned piece; the moment of inertia is for rectangular coördinates. So it is merely a convenience to represent the right-hand member of the equation by a simple expression, as in Equation [20]; then

$$\frac{T'\pi D^3}{32} = M_{be} \ldots\ldots\ldots\ldots\ldots\ldots [C]$$

The first part of Equation [B] is in the form of the resistance to torsion of a circular-sectioned piece, as a letter S', denoting shear, has been wrongfully employed: the moment of inertia is for polar coördinates. So it is convenient to use a simple term for the right-hand member, as shown in Equation [22]. Then

$$\frac{S'\pi D^3}{16} = M_{te} \ldots\ldots\ldots\ldots\ldots\ldots [D]$$

Of course the results will be the same if the same numerical value is used for S' as for T' in their respective equations. But why is it necessary or advisable to try to introduce a letter representing shear S' into a formula which has been derived from tension stress T'?

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Nothing is gained and only confusion is likely to arise. It would be better to drop entirely Equations [22], [23] and [24], with the accompanying reading matter. Equation [21] is all that is necessary here.

Referring to Par. 62, the maximum apparent shear stress, as derived from Fig. 6, is found in Equation [30]:

$$S' = \tfrac{1}{2}\sqrt{4S^2 + T^2}$$

By putting in the values for S and T, using a round-sectioned piece, and equating the internal resistance moments to the external moment, this equation becomes:

$$\frac{S'\pi D^3}{16} = \sqrt{M_b^2 + M_t^2} = M_{te} \quad \text{[E]}$$

Compare this with Equation [31]. The first member rightfully involves *shear*, contains the polar moments of inertia and may be conveniently made equal to the simple expression M_{te}.

It is not necessary to try to bring in here Equation [32] which involves M_{be}. The steps omitted by the author would then read:

$$\frac{T'\pi D^3}{32} = \tfrac{1}{2}\sqrt{M_b^2 + M_t^2} = M_{be} \quad \text{[F]}$$

This artificially puts a tension value T' in the place of a shear value S'. As long as the same numerical value is assigned to each, the results will be the same from both Equations [E] and [F]. But nothing is gained here either. It would be well to leave Equation [32] out of the paragraph.

In Par. 17 the author has shown that if all four faces have compressive forces upon them, the strain is represented by

$$s_1 - s_2 y = \frac{C_1}{E} - \frac{C_2 y}{E} = \frac{C_{e_1}}{E}$$

and when the forces upon the faces are all tension, Par. 21,

$$T_{e_1} = T_1 - T_2 y - T_3 y$$

In each of these cases the strain involves the *difference*.

In Par. 33 he is apparently referring to a case where the forces become *tension* on two opposite faces *and compression* on the two opposite faces at right angles to the former. In this case also he has the strain and so the stress involve the *difference*.

$$\text{Strain} = \frac{T'}{E} - \frac{C'y}{E} \quad \text{[G]}$$

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Will he kindly use a figure of reference, akin to Fig. 4, and show clearly how he gets this expression, Equation [G]?

In Par. 8 the author has shown that, with two sets of compression loads acting, the maximum apparent unit shear stress is equal to

$$S' = \tfrac{1}{2}(C_1 - C_2)$$

and in Par. 9 that, for two sets of tension forces, it would be

$$S' = \tfrac{1}{2}(T_1 - T_2)$$

In Par. 20, for two sets of compression loads the maximum equivalent shear stress is

$$S_e = \tfrac{1}{2}(C_{e_1} - C_{e_2})$$

In each of these cases the *difference* is involved. Now in Par. 37 evidently the forces referred to are the apparent tensile force T' and the apparent compression force C' at right angles to the former. The statement as made for this case is

$$S_e = \tfrac{1}{2}(T_e - C_e) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [H]$$

In this case also the *difference* is used.

Will the author kindly add to his paper the derivation of this expression, Equation [H]? Referring to Pars. 69 and 70, y is used as 0.25 in one formula and 0.3 in the other. Is there any reason for this?

THE AUTHOR. Professor Sanborn's first question refers to Equations [22], [23] and [24], and he suggests that these be dropped. His question is answered in Par. 58. I quite agree that Equations [22], [23] and [24] should not be used in preference to those recommended in Pars. 69 and 70; but the fact that Equations [22] and [23] are given in many of our textbooks on the strength of materials and machine design justifies their introduction into this discussion. Equation [24] is the corrected form for Equation [22], and from the standpoint of the designer is the better of the two. It should be noted that the designer is more concerned with the strength than the stress of a member, and the above correction restrains him from ignoring the weaker resistance of the material.

Equation [E] is identical with Equation [31]. Equation [F] is not only absurd for the reasons given by him, but is subject to the same objections as Equation [22]. Equation [31] meets his objection to his own Equation [F], in that it holds true in so far as the factor of safety is concerned.

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In Equation [6], C' will always be negative. In Par. 33 the compression stress C' is negative and T' is positive. Hence

$$\frac{T'}{E} + (-C'y) = \frac{T'}{E} - C'y$$

and

$$T_e = T' - C'y$$

This permits of the substitution of T' and C' given in Equations [5] and [6] without changing the sign of C'. It is obvious that the total strain is the arithmetic sum of $\frac{T'}{E}$ and $\frac{C'y}{E}$, and by combining the equations as they are written the desired arithmetic summation is effected. When T' acts horizontally and C' vertically the strains would be represented as in Fig. 4 by having both dotted vertical lines to the right of the full line and both dotted horizontal lines above the full line representing the base.

The method used in Par. 33 was also used in Par. 37 in arriving at Equations [15] and [16]. Equation [H] is referred to in Par. 40, where it is stated that it is given in Merriman's Mechanics of Materials; it may be found on p. 365 of the tenth edition.

Poisson's ratio is less for cast iron and hard steel than for soft steel and copper. Merriman gives $\frac{1}{4}$ for cast iron and $\frac{1}{3}$ for steel. Hence, 0.25 was used for hard materials and 0.3 for soft materials in Pars. 69 and 70.

Particular attention is called to the allowable working values of T and S. For hard materials the value of T is based on the elastic strength in tension and for soft materials the value of S is based on the elastic strength of shear; for very soft materials such as steel tubing, T/S may be greater than 2 for equal factors of safety, in which case the equivalent-shear-stress formulæ give a 46 per cent greater equivalent bending moment and a 14 per cent greater diameter than the Grashof formula when $M_b = M_t$. The most reliable data for determining the allowable working stresses are obtained by testing hard materials in tension and soft materials in torsion.

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No. 1621

THE TRUMBLE REFINING PROCESS

By N. W. Thompson, San Francisco, Cal.
Member of the Society

Disadvantages of the method of distilling oils by filling a cylindrical still with the crude oil and boiling off the lighter distillates, then the next heavier, and so on, are: an expensive installation to build and maintain, low heat transfer, considerable radiation losses, etc.

The Trumble distilling apparatus is a departure from this method. The essential part of the apparatus is a vertical evaporating chamber, in which are arranged a number of umbrella-shaped "spreader hoods." Heat is applied to the chamber from the outside by any convenient method, and oil fed into the top of the chamber flows down over the hoods in a thin film, strikes against the interior wall of the chamber and flows down. The vapor evolved passes up through a centrally disposed take-off pipe into a separator.

The paper embodies a description of an actual plant employing the system.

The chief advantage claimed for the system is the conservation of heat. It is stated that the plant described is doing on 1.1 per cent of the crude oil run through as fuel more work than large oil refineries operating today using as fuel 4 per cent of the crude oil.

THE first step in the refining of oils is to obtain the different fractions or distillates of the crude oil. Some of these are ready marketable products and others need treatment. To obtain these distillates it is necessary to distill or boil them over in a still and separate them according to boiling points.

OLD METHOD OF OBTAINING DISTILLATES

2 The old method was to fill a cylindrical still with the crude oil and boil off the lighter distillates, then the next heavier, and so on. After being condensed these distillates were run through a steam still and the still kept to a certain temperature until all of the lighter fraction or first cut was obtained, then the temperature was raised for the next fraction, and so on.

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers. Contributed by the San Francisco Section.

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3 A large number of the refineries at the present time continue this system, and others put a number of crude stills in series and run them continuously; that is, the residuum or bottoms of the first still run to the second still where they are heated to a higher temperature, and so on to the last still, from which the residuum flows to a cooler and then to the tank. This residuum is generally fuel oil.

4 In these stills there is a large volume of oil over the fires and also an expensive installation to build and maintain. There can be no seams in the bottom of the stills necessitating very large plates, and it is necessary to have perforated steam pipes in the bottoms to agitate the oil so as to keep the bottoms from burning, etc.

5 Large surfaces are necessary when the heating is done in this way. There is low heat transfer on account of slow velocities and the low specific heat of the liquid, and about one-third of the surface of the still cannot be heated and must be highly insulated to avoid excessive radiation. However, the radiation losses are considerable even in the best settings.

TRUMBLE DISTILLING APPARATUS

6 The Trumble distilling apparatus is quite a departure from that used in the method described and has proved very successful in the plants where it has been installed. The principal parts of the apparatus are shown in Figs. 1, 2 and 3.

7 In Fig. 1 is shown a Trumble evaporator, to which in this case is connected an evaporator column. The evaporator consists of a closed cylindrical metal shell, vertically disposed, to which heat is applied from the outside in any convenient manner, as, for example, by flue gases or by vapors from another evaporator.

8 Inside the evaporating chamber is arranged a central vertical pipe having umbrella-shaped devices attached thereto at intervals, which are called "spreader hoods," so that oil fed to the apex of these hoods will flow down over their sides in a thin film after the analogy of rain flowing down the outside of an umbrella. The lower edges of these hoods are at a little distance from the sides of the wall of the evaporating chamber, and in operation the oil flows down and over the hood and strikes against the interior wall of the evaporating chamber and flows down the wall in a thin continuous film.

9 In case any of the oil should not strike against the wall in the evaporating chamber, but should drop off the edge of the hood and fall vertically; or in case there should be a tendency to bubbling or

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foaming on the wall of the evaporating chamber whereby a portion of the oil may be thrown back toward the center of the evaporating chamber, such oil will be caught by the next spreader hood and will flow down the surface thereof, thereby insuring an ultimate spreading of the oil on the wall of the evaporating chamber.

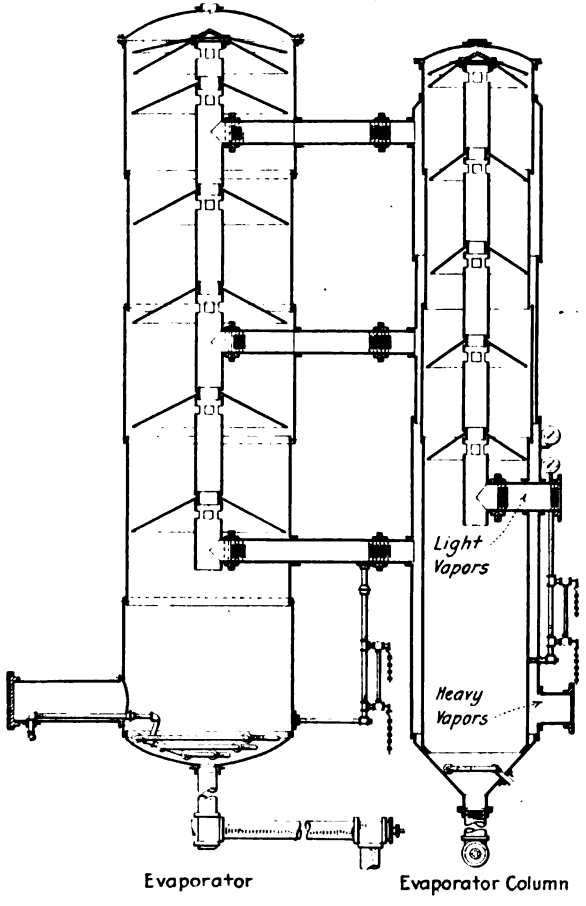

FIG. 1 EVAPORATOR AND EVAPORATOR COLUMN

10 The oil to be operated on is fed through a supply pipe to the top of the evaporating chamber and discharges downward on the apex of the uppermost hood. The oil then flows down this hood in a thin stream and is delivered against the interior wall of the evaporating chamber as herein above described.

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11 The centrally arranged vapor take-off pipe in the evaporating chamber, to which the spreader hoods are attached, is provided with perforations underneath each of the hoods, and through these perforations the vapors pass from the evaporating chamber into the vapor take-off pipe. Located in this vapor take-off pipe are lateral branch pipes, and these branches extend through the wall of the evaporating chamber to the outside of the apparatus.

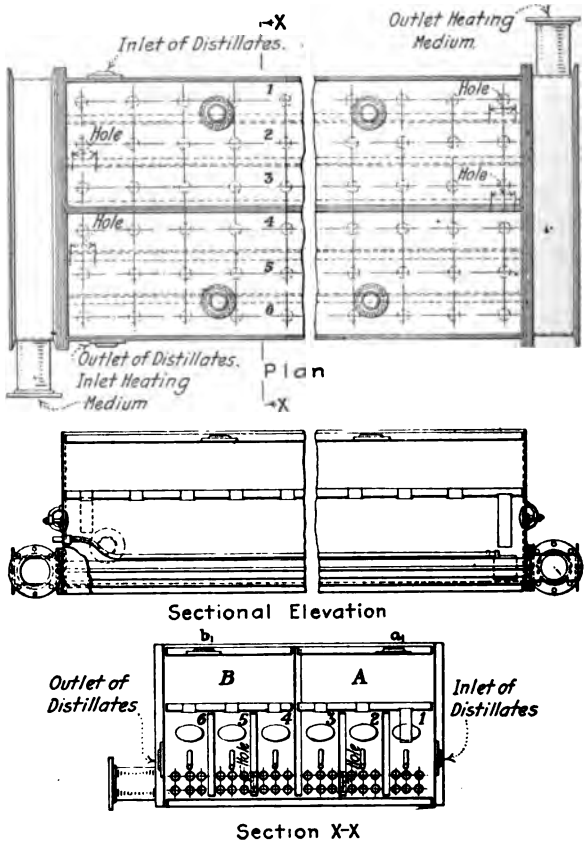

FIG. 2 SEPARATOR

12 Fig. 2 shows the construction of the separator. This is a re-run still for distillates from bottoms of dephlegmators, or from any other source, if these need fractionating. The distillate flows into compartment (1) over a number of pipes through which a heating medium is passed, either residuum or vapors as the case may be, and

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then passes through an opening at end of compartment (1) into compartment (2) and back through compartment (3) and so on, leaving at end of compartment (6). The vapors evolved in compartments (1), (2) and (3) pass through openings into vapor compartment B and out through opening b_1 to condenser, etc.

13 The manifolds on the ends of the separators are provided with covers having stuffing boxes through which valves are operated to regulate the flow through tubes in each compartment, thereby controlling the heat in these compartments.

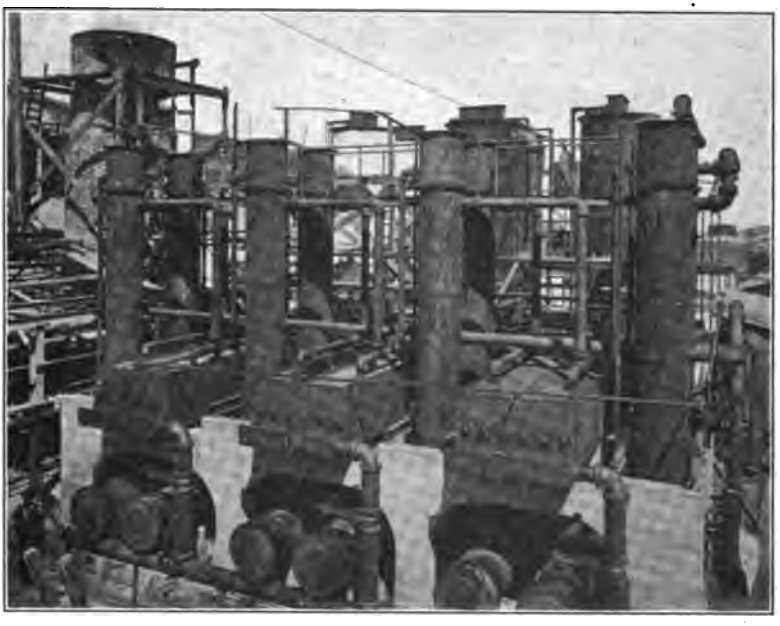

FIG. 3 GENERAL ARRANGEMENT OF PLANT

DESCRIPTION OF PLANT EMPLOYING TRUMBLE SYSTEM

14 The illustrations, Figs. 3 to 6 inclusive, are from photographs taken during the construction of a plant employing the Trumble system. Fig. 3 gives a general view. In the foreground, at the left, is the pipe heater, and located in the brick stack at the left is the evaporator. In the distance are the dephlegmators, in the foreground the separators and the vertical condensers for the vapors from the separators. Under the arches are the coolers for the distillates. The pipe lines in the trench are the distillate lines

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from the condensers and coolers carrying the cooled products to the receiving boxes. The arrangement of these receiving boxes is shown in Fig. 4. Behind the boxes are dewatering traps for separating the water from the distillates. Fig. 5 shows the dephlegmators with the heat exchangers underneath. Fig. 6 shows the operating valves for the distillates from the dephlegmators. These valves as well as all operating valves are handled from one platform.

15 All plants are designed to meet the conditions under which they are to be used, but they are very flexible and are able to take

FIG. 4 ARRANGEMENT OF RECEIVING BOXES

care of a very wide range of conditions by controlling the heat of the furnace and the velocity of the oil which runs through it. It will be impossible to go into the many different arrangements of plant design, but the following will make clear the running of a typical and successful plant.

FLOW OF OIL THROUGH PLANT

16 The flow of the crude oil through the plant is indicated by the flow sheet in Fig. 7. The oil enters through a 6-in. line and is used as a cooling medium in the six coolers shown. These coolers

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are of the horizontal tubular type, 30 in. in diameter, with sixty-two 2-in. by 18-ft. tubes. The oil enters at the bottom and passes through the tubes, making four passes, and comes out at the top and goes into a header through which it passes into the four heat exchangers or coolers for the residuum.

17 These heat exchangers are 48 in. in diameter and have 178 2-in. by 18-ft. tubes. The crude oil enters the first heat exchanger at the bottom and passes through the tubes, making six passes, and out at the top into the bottom of the next exchanger, and so on,

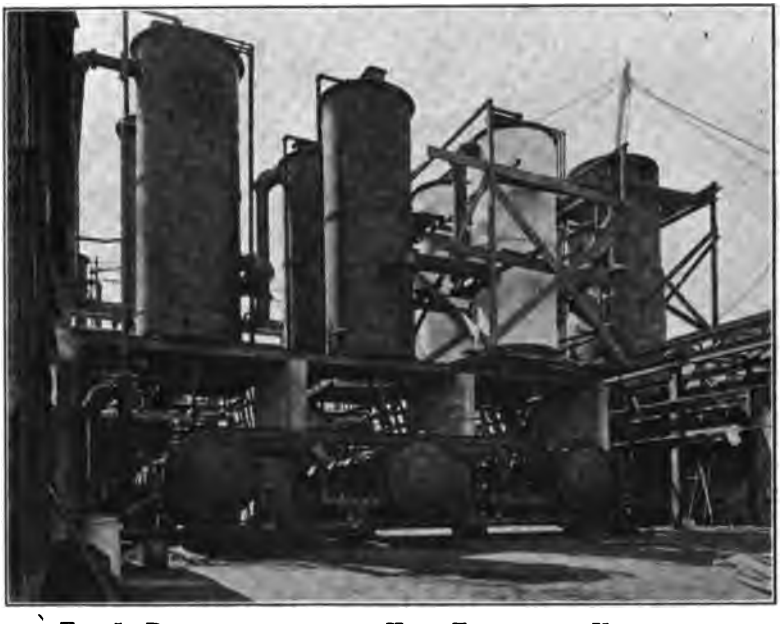

FIG. 5 DEPHLEGMATORS WITH HEAT EXCHANGERS UNDERNEATH

to the heater pipes, where it is split in two, each half passing in series through seventy-two 18¾-ft. lengths of 4-in. pipe, flowing back and forth and upward at all times, and then into the top of the evaporator, where it flows down the sides in a thin film.

18 The oil in passing through the heater pipes and evaporator is heated by the flue gases. The vapors evolved are separated in the evaporator and taken care of later. The oil is maintained at a constant level in the bottom of the evaporator and runs out of the bottom of it as residuum. A perforated steam coil is placed in the bottom of the evaporator under the liquid and superheated steam

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is passed through it in order to drive off any of the lighter distillates which may drop back from the vapors. However, very little steam is necessary in this case as the heat losses are supplied by the flue gases.

19 After leaving the evaporator the residuum is used as a heating medium for redistilling the distillates passing through separators, and then flows through the heat exchangers counter-current to the crude oil. The residuum enters the first heat exchanger at the top and makes two passes around the tubes and out at the bottom, then into top of the second exchanger and so on through the five

FIG. 6 OPERATING VALVES FOR DISTILLATES FROM DEPHLEGMATORS

heat exchangers and through a standpipe, which is vented and which controls the head of residuum in the bottom of the evaporator, and then to the storage tanks.

20 Having followed the course of the crude oil through the apparatus, showing the separation of it into vapors and residuum, it remains to dispose of the vapors shown on the flow chart in Fig. 8. The vapors from the central vapor column of the evaporator are taken out through a shell and connected into a header. The vapors pass from this header through an oil catcher similar to a steam separator, the condensate passing out of the bottom of it into the

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bottom of the evaporator. They then pass through six large dephlegmators in series, flowing into the bottom of each and out at the top. In each dephlegmator a partial condensing of the vapor takes place, thus forming a liquid in the bottom of that particular dephlegmator. From some of the dephlegmators this condensed liquid is a ready product — from others it is just between two different products.

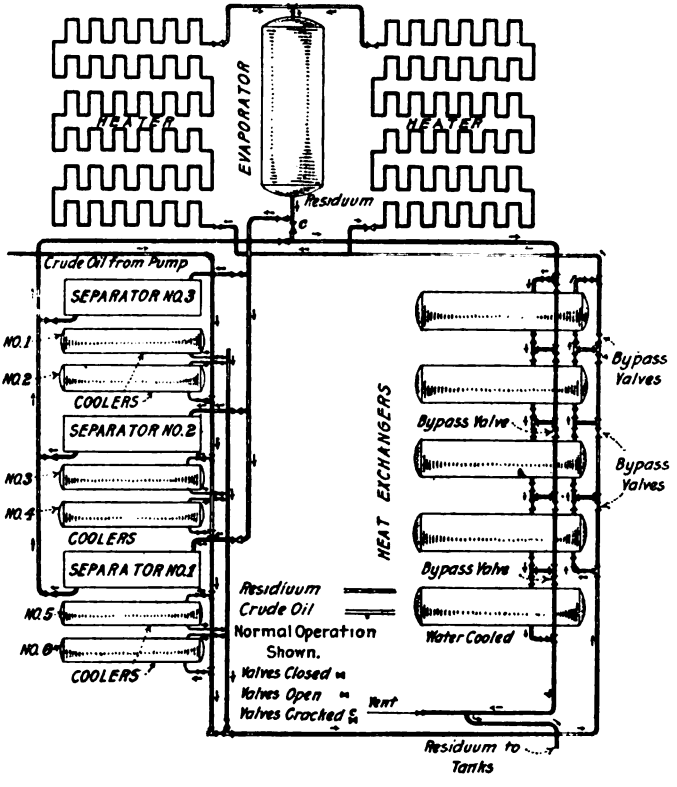

FIG. 7 CRUDE OIL AND RESIDUUM SYSTEM

21 A system of water circulation is used as a cooling medium for the vapors from the dephlegmators and separators. The vapors are cooled in vertical tubular condensers and about twenty barrels of water are required per barrel of distillate cooled. Superheated steam is used in the bottom of the evaporators, separators and dephlegmators as an agitator to relieve the lower-boiling-point fractions from the bottoms. About 30 lb. of steam are used to each barrel of distillate produced.

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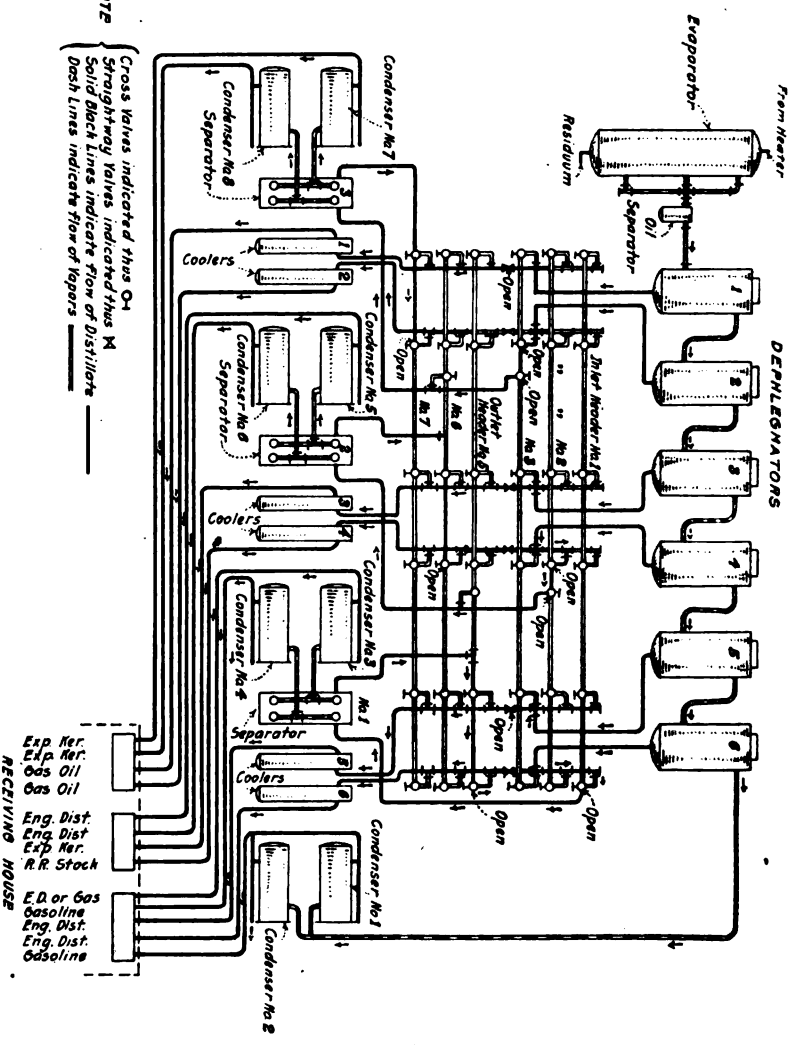

FIG. 8 VAPOR AND DISTILLATE SYSTEM

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INSTALLATIONS OF THE SYSTEM

22 The company for whom this plant was installed has two Trumble plants in operation, — the No. 2 plant, above, and the No. 1 plant. The No. 1 plant differs from the No. 2 plant in that an evaporator column is used with the evaporator and two fractions of vapors are given off. These vapors are used as a heating medium in separators and are then condensed and run back to the separators and fractionated in same. When this plant was first started the fractionating of the distillates was not close enough for ready products and some of the products had to be re-run. After a few experiments small dephlegmators were installed on the vapor lines from the separators, and from that time on there has been no occasion to re-run any of the distillates.

23 With these two Trumble plants in operation continuously for eight months, the company has averaged a run of 16,000 bbl. of crude oil per day of 24 hours through both plants, 30 per cent of this crude oil being vaporized and fractionated into readily marketable distillate products. During this time 1.1 per cent of the total amount of crude oil run was used as fuel to do this work, and the refining losses were 0.75 per cent of the total amount of crude oil run.

24 Five men are required for operating the two plants per shift, i.e., one head stillman over both plants, one stillman at each plant, one fireman for both plants, and one receiving-house man for both plants.

25 The Trumble system has been successful from the very first installation. The Santa Fé Railroad Company has used the system in the Midway oil fields with success. The first expansion or evaporating chamber used for this installation was made by joining two old boilers together, end to end, while the rest of the apparatus was either made in the shops of the company, in the field or was picked up on the property. This plant, composed of remnants, so to speak, worked from the very start and uninterruptedly for several years — in fact, up to the time the Santa Fé made a trade of the oil on their grounds for a heavier oil delivered at Mojave, a division point on their main lines.

26 There was no demand for perfect separation of the distillates at this plant, but a rough refining was done. Two products were made from the tops, one being 53 deg., while the other was from that point down to about stove distillate. The 53-deg. cut was water-white and was generally used in automobile engines by the Santa

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Fé on their Midway property. The distillates produced sold at profitable figures and were much sought after.

27 One of the main benefits claimed to be secured by the use of this form of still is that the oil while being heated or when giving off its vapors is never exposed to any action tending to "crack" or break down the molecular structure. As proof of this, it is particularly pointed out that one can never detect any odor of marsh gas around a plant of this kind, which is so apparent in all other forms of oil-distilling plants.

28 This absence of "cracking" and resultant freeing of carbon led up to the adoption of the process in making asphaltum for all purposes, but more especially that used in road work. The first plant of this kind was installed for the John R. Ott Company and produced oils for road work which secured much better prices than other refineries were able to secure, for the reason that the oils had greater viscosity, toughness and lasting qualities owing to the complete absence of free carbon, which, as every engineer knows, causes the asphaltum to break, or what is commonly termed, to "short." The Ott Company was afterwards disposed of to a company owning wells producing heavy oils in the Santa Maria fields, and a larger plant was erected there; and it is quite safe to say that a large percentage of the roadways of California are now either coated with or contain asphaltum treated in this plant.

29 Another instance of the successful use of this system for manufacturing asphaltum is the Warner Quinlay Asphalt Company, which has its refinery at Warner, New Jersey. This plant has been making a high-grade asphaltum for a number of years by this process with uninterrupted success. Their goods have found favor in the markets on account of their ability to produce any quantity of any grade having the same penetration, a thing impossible to obtain where the individual still and batch method is followed. It is only necessary with the Trumble process to raise and maintain the required degree of temperature, and the product therefrom will be absolutely uniform, no matter whether it is one hundred tons or one hundred thousand tons. Again, when a different penetration is required, the flow of oil may be either hastened or retarded, and the desired product derived. The same results are secured by regulation of fires.

30 For instance, a certain number of tons of a certain grade of asphaltum may be called for. The stillman regulates flow of oil or fires to produce the desired results. When the required amount has

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been produced he simply makes his changes in oil flow or fire regulation to produce the asphaltum of any other desired specification. No cooling down of stills or cleaning out is required.

31 The oil in passing through the entire apparatus is not subjected to the direct heat for any great period of time and at no time is it in a quiescent condition, which generally tends to burn or coke it, thus leaving coke on the iron, which, if not removed, soon causes the burning out of the still.

ECONOMY OF THE SYSTEM

32 At the present time the necessity for conserving the fuel oil and labor around an oil refinery is imperative. The whole subject is a matter of heat units and their proper conservation.

33 In the Trumble system the products to be re-run in the separators are condensed but not cooled, thereby saving heat. The oil is in a very thin film on the shell of the evaporator and is being heated in its downward flow. The vapors being evolved have a free relief and have no opportunity of dropping back into the residuum.

34 There is considerable work for the mechanical engineer in the conservation of heat units around an oil refinery and in most all branches of the oil industry. There are large refineries operating today and using four to five hundred per cent more fuel than is necessary to do the work. It is possible to save, by proper distribution of the heat available around the oil refineries in the United States, at least 2 per cent of the total crude oil put through these refineries. There are large oil refineries operating today that are using as fuel 4 per cent of the crude oil run through them to do less work than the plant described is doing on 1.1 per cent of the crude oil run through as fuel, and the losses due to non-condensable gases, etc., are 2 per cent against 0.75 per cent.

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No. 1622

THE SUBMARINE

By C. H. Bedell,[1] Groton, Conn.
Non-Member

After a few brief historical notes on early hand-propelled submarines, the author describes Holland's first practical submarine, a construction made possible by employing the gasoline engine, storage batteries and electric motors — all then in process of development. He then deals with the construction, equipment and operation of the U. S. Submarine M-1, a boat 200 ft. in length, discussing such topics as the periscope, Diesel submarine engines, diving, balancing, the rescue of men from a sunken submarine, etc. Incidentally, several misconceptions under which the author of Twenty Thousand Leagues Under the Sea labored, are pointed out.

RECENT events have forcibly brought to the attention of the entire world the capabilities of the little boat known as the submarine. All the characteristics of these boats are fascinating: to the engineer on account of the many unique problems that have to be solved; to all of us on account of the many dramatic possibilities in connection with submarine navigation. Since these dramatic possibilities are so great in number, it is surprising that our popular fiction writers have not made more extended use of the submarine. Probably this neglect of such a promising field has been due to lack of the necessary engineering knowledge to handle the subject properly. We have, however, one book on the submarine in the field of fiction that is well written and full of interesting scientific and engineering material. This book is Jules Verne's Twenty Thousand Leagues Under the Sea. I read it as a boy, when it was first published in about 1874, and was fascinated by the picture it gave of life beneath the wave, not imagining that it would ever be my privilege to journey thus in those depths of which we know so little. A short time ago I reread the book, and was again fascinated by it, because it gave me a chance to see how closely we have lived up to that imaginary picture of Jules Verne.

[1] Electrical Engineer, Electric Boat Co.

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers. Contributed by the New York Section.

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2 As far as the handling of a submarine is concerned, whether under way, on the surface or submerged, or at rest on the surface, poised at any depth or resting on the bottom, the boats of the present day are as perfect as the *Nautilus* of Jules Verne. We may even, if we so desire, make our boat so that, when it is at rest submerged, a man with a diving helmet, and entirely disconnected from the submarine or the surface, may pass from it into the sea and explore the ocean floor for an hour or more, as Captain Nemo of the *Nautilus* did. That such construction is not used is due to the fact that there seems to be no material need for such operations. The *Nautilus* was driven by electricity. We also use electricity when running submerged, but we obtain our electricity from storage batteries, while Captain Nemo obtained his in some mysterious way from the sea itself. The great difference between fiction and reality in this case is that the *Nautilus* was able to go around the world with one supply of energy, while we are obliged to come to the surface after one or two hundred miles for the purpose of recharging our storage batteries.

3 The men on the *Nautilus* are supposed to have been able to see objects at distances up to one-half or three-quarters of a mile by the light of the sun or by powerful electric lamps. While we at this time probably have more powerful electric lamps, it is impossible for us to see any great distance through water, no matter what method of lighting is used. This is true, at least, along our shores as far out as the Gulf Stream. An enormous amount of sediment is continually being poured into the sea by our rivers and streams, and in addition the endless wash of the waves on our sandy shores constantly tends to maintain the turbidity of the water. I have frequently looked through the periscope of a submarine when resting on the bottom at a depth of 50 ft. The second periscope, some five or six feet away, could easily be seen, but the bow of the boat, 75 ft. away, could not be seen. The suspended matter in the water acts exactly as does fog in the air in preventing distant vision. On account of this fact, all running when totally submerged must be by distance run, obtained by known speed and time. Of course, in certain waters the limit of vision may be materially increased, as, for example, among the islands of the West Indies or off the coast of Southern California, yet even in such waters it is not probable that one could see more than 100 or 200 ft., and such a distance is not sufficient for purposes of navigation. Thus at one stroke we take away the greatest factor that

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gives such a charm to Verne's work — the major portion of the control of the submarine must be by vision above the waves.

4 Another point interesting to consider is that of the pressure per square inch at different depths, for in this connection Jules Verne materially slipped up in his calculations. He tells about Captain Nemo forcing his boat to depths of 6000 or 7000 ft., not realizing that pressures increase nearly half a pound per square inch for each added foot of depth. At 6000 ft. the pressure is nearly 3000 lb. per sq. in., and the *Nautilus*, as described in Verne's work, would not have stood any such pressure. An illustration in the book shows a man seated before a large plate-glass window, and another man swimming in the water outside. This window must have had an area of at least 25 sq. ft., and at a depth of 200 ft. it would have to sustain a pressure of about 100 lb. per sq. in., or 175 tons on the window. At 6000 ft. the total pressure would be 5250 tons. Certainly no glass made of the form illustrated could sustain such a load. However, it makes a very pretty picture.

5 Another point shows Verne's misunderstanding. He states that they had to use all the enormous power of her engines to force the boat down against the great water pressure; the greater the pressure, the greater power it took. This is not according to fact, for if a body is once made heavier than sea water and starts to sink, it will continue until the bottom is reached, if the salt in the sea water remains a constant percentage, a condition which practically exists in the open sea.

6 The question is frequently raised in our newspapers whether a ship sunk by collision or the like will sink to the bottom or go a certain distance and then remain poised. The question was raised at the time the *Titanic* was sunk. The solution of the question rests upon the compressibility of the material of the ship as compared with that of water. If the latter is greater than the former, and the depth is great enough, a point would be reached where the water would be as dense as the material of the ship, and there the ship would remain poised.

7 For the purpose of calculation, let us take the extreme case of a solid steel ball dropped overboard in the open sea. Now, in general, we say that water is incompressible. This statement arose in comparing the compressibility of water with that of a gas, such as steam. When an engineer allows water to get from his boiler into his engine cylinder, and the piston striking this water on the return stroke drives off the cylinder head, he says the water

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is incompressible. As compared to a gas it is incompressible, but as compared to steel it is compressible; indeed, it is more compressible than steel. Therefore, our steel ball as it descends into the sea and is compressed has water around it that is being compressed at a more rapid rate under the increase of pressure than the steel. If the depth, and therefore the pressure, is great enough, a point will be reached where the water will be as dense as the steel, and at that point the ball will remain suspended. A calculation based on the compressibility of steel and water shows that the required depth is about 100 miles. As the sea is only some five or six miles deep, it is evident that our steel ball will go to the bottom.

8 Now let us take the case of the ship that has been sunk. When she starts to go down she is heavier than the water around her. The ship, as a whole, is far more compressible than the steel of our ball, and will get relatively heavier as she descends, that is, will sink faster and faster until the bottom is reached.

9 Returning now to the submarine, where we have a hull that is perfectly watertight. Since this hull is composed of circular frames on which is mounted the hull plating, its compressibility is far greater than that of our steel ball; indeed, than that of water. In consequence, if a submarine is so trimmed down that she is even slightly heavier than water, she will sink to the bottom. This has been conclusively proved in connection with our tests of submarines at 200 ft. Every submarine for the U. S. Government must be taken down to this depth and kept there for ten minutes. In making this test, it is the custom first to anchor the boat where the depth of the water is right, then trim the boat by admitting water into her tanks, trimming her down until she has only a few hundred pounds' buoyancy, then hauling in on the anchor rope. This operation draws the boat down until the desired depth is reached. In one or two cases, in the trimming-down operation, but a small amount of reserved buoyancy was given the boat, and as the boat descended and became compressed this reserved buoyancy was lost and the boat went the rest of the way to the bottom.

10 From the above it will be readily seen that Verne's statement that it took all the power of the engines of the *Nautilus* to drive her into those great depths is not correct. There is one exception to the general statement that a body starting to sink will go to the bottom, and this is where the water is stratified, when large quantities of fresh water from rivers come in contact with the salt sea water. Such a condition exists in the St. Lawrence. Re-

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cently in making the 200-ft. depth test in those waters it was found necessary to add 5000 lb. to the water in the tanks after the boat had started to sink in order to get her down to 200 ft. This was due to the fact that the fresh water from the river was over the heavier salt sea water.

THE SUBMARINE IN HISTORY

11 The history of the submarine extends over quite a period of time, as there is a record of such a boat having been built about the year 1624. During the next 150 years the subject was frequently considered by marine engineers, but no construction was undertaken. At the time of our Revolutionary War the interest in the subject was transferred from Europe to this country, due to the fact that a small submarine had been built by David Bushnell, of Connecticut. This boat was only large enough for one man and shaped like a flattened egg, with its major axis vertical. It was fitted with tanks and pumps, anchor operated from the inside of the boat, screw propeller in the front of the boat, another screw propeller at the top with its axis vertical, rudder and torpedo at the stern, and at the top of the boat a screw operated from within the boat. It is evident that this screw was intended to be worked into the planking of a ship at anchor. The torpedo was fastened to the screw by a line, and when the submarine was moved away the torpedo remained with the screw. The separating of the torpedo from the submarine started a clock, which in a certain time would explode the torpedo.

12 Bushnell had to educate the public on two points in connection with his boat, the exploding of gunpowder under water and the use of the screw propeller. The propeller had been invented a short time before by another man, but evidently Bushnell's boat was the first on which it was used. During the Revolutionary War a chance at last came to make use of the boat, against a British war ship anchored off Governors Island. Unfortunately, the man who had been conducting the operations of the boat was sick at the time and another had to take his place. Floating down with the tide in the late hours of the night, the submarine was maneuvered until she came under the war ship. The operator in attempting to force the screw into the planking of the ship failed on account of striking metal fittings. Before he could relocate his boat the tide carried him away and he had to give up the attempt.

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13 Two other attempts were made against British ships anchored in the Hudson, but these also failed on account of the strong tide. If the anchor of the submarine had been used until the torpedo was attached to the ship, the attempt would have been successful. Public opinion did not support Bushnell in his work, and therefore nothing further was done.

14 The next submarine of interest is that of Robert Fulton, who launched the *Nautilus* in the Seine in 1801. He conducted many experiments with this boat, but not getting the necessary financial support in France, took the boat over to England. There he created quite a furor, and many experiments were conducted, even going so far as to the blowing up of an old hulk provided for the purpose. The people did not consider the time ripe for that method of warfare, and Fulton again failed to get support. He then came over to this country and succeeded in obtaining a grant of $50,000 from Congress for the conducting of experiments. It is understood that it was Fulton's submarine that was to make an attack on a British prison ship off New London, but the commander of the prison ship hid behind his prisoners and obtained the influence of their friends on shore to prevent the attack. The work with Fulton's submarine was discontinued, as again it seemed that popular opinion was not ready for the use of such ships.

15 The credit for the first actual service of a submarine in time of war will have to be given to a boat built by Wilhelm Bauer, a Bavarian, who built one such boat for Germany and one for Russia. The boat built for Germany succeeded in breaking up the blockade of the Danish fleet off Kiel. Later, this boat was sunk, due to the collapse of her hull from excessive water pressure, the crew luckily escaping. A few years ago the boat was located during certain dredging operations, was raised, and is now on exhibition in Berlin.

16 During our Civil War the South became quite interested in the submarine, and several of the boats, called "Davids," were built. These, as were the earlier boats, were all operated by man power, eight men being used to drive the propeller. Many accidents were experienced during the experiments on these boats and several crews were lost. These accidents, however, did not occur when the boats were operating submerged but when on the surface. The small conning tower used was very low, and waves from passing steamers and the like washed over it, causing the boat to sink. New crews were quickly found and experiments continued. At

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last a chance to use the boat came, and an attack was made on the U. S. frigate *Housatonic*, anchored off Charleston. The attack was made at night, and therefore the boat was operated on the surface only. A spar torpedo was used, as at that time the automobile torpedo had not been developed. It is reported that an officer on the deck of the *Housatonic* saw the submarine approaching the ship, but thought it was a plank floating with the tide. This idea was quickly dispelled, for after a terrific explosion the men who had been on deck found themselves in the water. The *Housatonic* was sunk, and carried down with her the submarine and all her brave crew. It is probable that the smaller boat was sucked into the hole in the larger ship, and held there by the water pressure.

PRESENT-DAY SUBMARINES

17 During the following twenty-five years many submarines were designed and a few built. None of these, however, proved to be successful. I am going, therefore, to jump to the time of John P. Holland, and describe the submarine of the present day. Holland was an Irishman who came to this country just before the Civil War, a man of but very little education but of bright mind. He was much interested in the fight between the *Monitor* and the *Merrimac*, and soon commenced to consider submarine work. At last he succeeded in getting support for his experiments and built two or three small submarines. His idea being to build a boat that would sink the British Navy, his trend of mind is shown by the name he gave one of his boats, the *Finian Ram*. His first boats did not amount to much, but he acquired a great deal of experience, discovered what to do and what to avoid, and was then in shape to attempt more extended work. It was at this time that he joined forces with the Electric Boat Company, and the *Holland* was their first product.

18 Mr. Holland started his work at just the right time, for the internal-combustion gasoline engine giving large power with small space and weight had just been developed and large storage batteries with corresponding electric motors were to be had. Without this material it is safe to say the submarine would still be in an experimental form.

19 The general arrangement of the modern submarine follows very closely the design given in sketch form in Fig. 1. The hull proper is cigar-shaped, since this form is best suited to withstand

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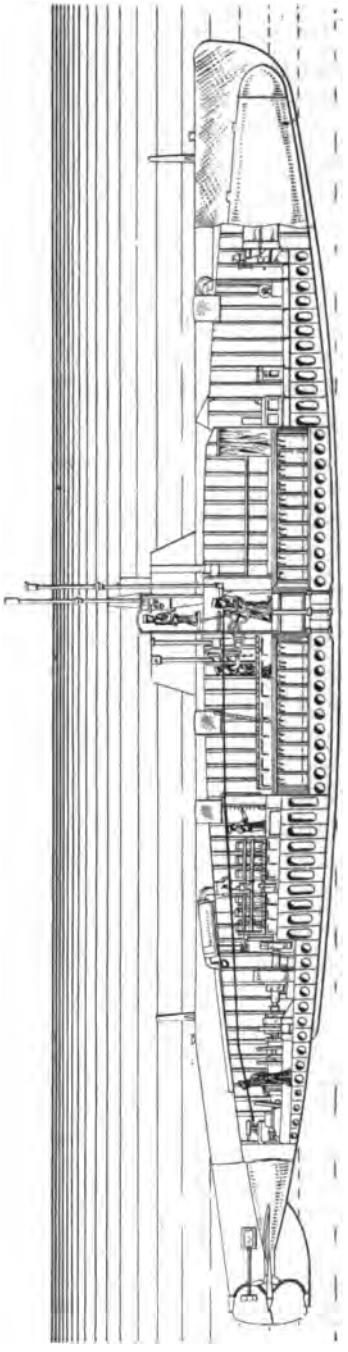

FIG. 1 CROSS-SECTION OF A MODERN SUBMARINE

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the pressure of submergence. Above the main hull is a narrow superstructure extending from the bow nearly to the stern. This superstructure may be watertight, but in general is open to the sea. It serves to house certain external fittings, and forms a deck for the use of the crew. At the bow just within the bow casting is the bow cap, covering the outer ends of four torpedo tubes; two openings are made through this bow cap, and by rotating the cap the openings may be placed in line with the different torpedo tubes. These tubes at the inboard end are fitted with doors, so that after the tubes have had the water drained into the trimming tank which surrounds them, the doors may be opened for the admission of spare torpedoes. Immediately abaft the tubes is space for spare torpedoes, and below the deck, tanks for fuel. In the design shown the galley is also located in this compartment. In the central part of the boat is the main operating compartment, in which are the levers that control the main ballast, auxiliary ballast, and adjusting tanks, steering and diving wheels, control of all high-pressure air lines, periscope and connection to the conning tower. In the two compartments ahead and abaft the central operating compartment are placed the two sections of the storage battery, these batteries being large enough to supply current to the main motors and drive the boat for one hour at 11½ knots, or at low speed to give her a radius of about 100 miles. Around the storage battery are the main ballast tanks.

20 It is in connection with the ballast tanks of a submarine that Mr. Holland showed his genius, and no submarine can be considered a success that does not follow the lines of tank construction that he prescribed. In all the earlier submarines the tanks were constructed without subdivision and large enough to take the maximum amount of water that might be required, and therefore were almost never totally filled. In consequence, as the angle of the boat changed, the water was free to flow from one end of the tank to the other, making it almost impossible to keep the boat properly trimmed. Holland, realizing the condition, made it a rule that the main ballast tanks should be of such a capacity that when entirely filled the boat would be brought to the awash condition only, and that the final adjusting of the buoyancy of the boat must be made by the use of a small tank which would have but a small free-water surface if not entirely filled. The main ballast tanks are therefore entirely empty or completely filled. Abaft the storage-battery compartment are the engines, main motors, pumps, air

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compressors, and at the stern are the after-trimming tank, twin-screw propellers and the steering and diving rudders. The conning tower is placed over the central operating compartment and in the sketch shown is fitted with one of the periscopes. Steering is done by means of an electric motor controlled by push buttons.

21 The operation of a boat submerged is quite different from one on the surface. On the surface if a man walks from amidships to the bow, the bow will be depressed, displacing a greater amount

FIG. 2 U. S. SUBMARINE *Holland*

of water, and therefore able to sustain the increased weight. When the boat is submerged no change of displacement can occur, and consequently such shifting of weight will cause the boat to take a greater angle. A boat submerged may be likened to a pendulum having a length equal to the distance between the center of buoyancy of the boat and its center of gravity, generally a distance of about sixteen inches, and the weight of the pendulum being the weight of the boat, say 500 tons. A weight moved from amidships to one end of the boat would produce a leverage to swing this pendulum from the vertical, in other words, to cause the boat to take an angle by the bow or stern. As a submarine when submerged will go the way she is pointed, it will readily be seen that change of angle will cause her to change her depth. The man at the diving wheel not only has his wheel and depth gage before him, but also a clinometer, a sort of level by which he can tell the exact angle

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of the ship and therefore tell whether the boat will change her depth or not as she goes along. As a matter of fact, the boat is swinging up or down most of the time, and it is the duty of the man at the diving wheel to check these motions and control the boat so that she will remain at the depth desired. It is a duty requiring constant attention, and the man at the diving wheel can perform no other duty. In the small boats first built great care was exercised that there should be no shifting of weight when the boat was running

FIG. 3 U. S. SUBMARINE *M-1*

submerged. In the large boats as now built the weight of a man is such a small percentage of the total weight that the ordinary movements of the crew may be counteracted by the man at the diving wheel.

EQUIPMENT OF SUBMARINES

22 From the *Holland* (see Fig. 2), having a length of about 53 ft., to the *M-1* (Fig. 3), with a length about 200 ft., is quite a change, yet a torpedo from a small boat, if it reaches its mark, is as effective as one from a large boat. It is the fact just mentioned that indicates why a submarine will retain her usefulness until she is literally worn out. She does not become obsolete as does a battleship as soon as a more powerful ship is constructed. The little *Holland* was thus in commission until worn out. Every other submarine built for the U. S. Government is in active service.

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23 At the time the *Holland* was built we had no periscopes. In consequence, the boat had to be handled by "porpoising," that is, running a short distance submerged and then coming to the

FIG. 4 LAUNCHING A SUBMARINE

FIG. 5 BOW OF SUBMARINE WITH BOW CAP IN POSITION FOR TORPEDO FIRING

surface far enough to expose the conning tower, thus getting a chance for a look around, and then diving. This porpoising can be done very quickly; the boat can pass from the depth of 30 ft. to the surface, line up on the target, have the torpedo fired, and

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be again below, all in 30 seconds. The advent of the periscope greatly aided submerged navigation, since at all times vision may be had without exposing the hull to the danger of a chance shot.

FIG. 6 STERN OF A SUBMARINE

FIG. 7 TAKING A TORPEDO ON BOARD

The increased size of the boats has made them far more comfortable, and better sea boats (compare the freeboard of the *Holland* with that of the *M-1*), and better adapted for long service at sea. The development of wireless telegraphy now permits the submarine to

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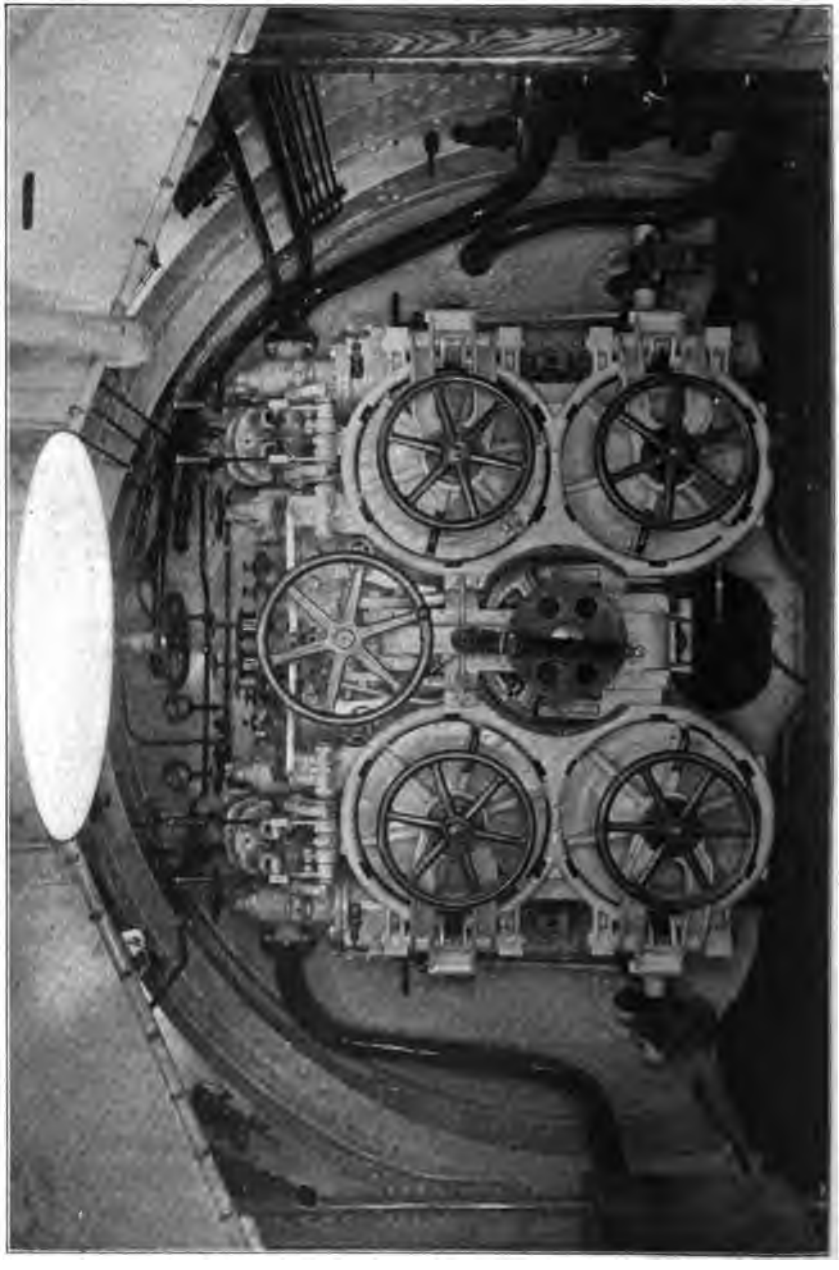

FIG. 8. INNER END OF THE FOUR TORPEDO TUBES

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keep in touch with the shore, and all submarines are now equipped with this wonderful apparatus, the tall masts required being so constructed that they may be quickly lowered for submerged work.

24 In the design of a submarine a far greater amount of preliminary work in the line of calculating of weights, disposal of equipment, etc., has to be done than with a surface boat, for not only is there a double motive-power equipment, but the boat must be designed for both surface and submerged work, with all the complicated control apparatus required. Some idea of this construction may be obtained from the illustrations given. Fig. 4 shows the launching of a submarine, the cigar shape of the main

FIG. 9 DIVING CONTROL STATION

hull giving sufficient strength to withstand the pressure of 200 ft. submergence, that is, nearly 100 lb. per sq. in. Fig. 5 represents the bow of a submarine before launching; it shows the bow cap with opening in line with the torpedo tube. When it is desired to close the tubes, the openings of the bow cap are placed under the bow casting. In Fig. 6 we have the stern of a submarine. In addition to the twin screws and steering rudder as used on a surface boat, the submarine has the horizontal diving rudder for steering the boat in the vertical plane. Each submarine can carry at least eight torpedoes. Fig. 7 shows the taking of a torpedo on board, and Fig. 8 shows the inner ends of the four torpedo tubes and escape hatch.

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25 A view of the diving station showing diving wheel and depth gages is given in Fig. 9. On the depth gage below the pointer is shown the curved glass tube of the clinometer. Fig. 10 reproduces a view taken through a periscope. The vertical line is the cross-wire and shows the exact direction the periscope is pointed. The scale at the top is a portion of the card of the periscope compass and shows that the periscope was pointed 76½ degrees from the north towards the east. The after end of the central operating compartment is shown in Fig. 11. This particular boat had an unusually large central operating compartment, at least four times as large as is usually constructed. The dark object at the top of

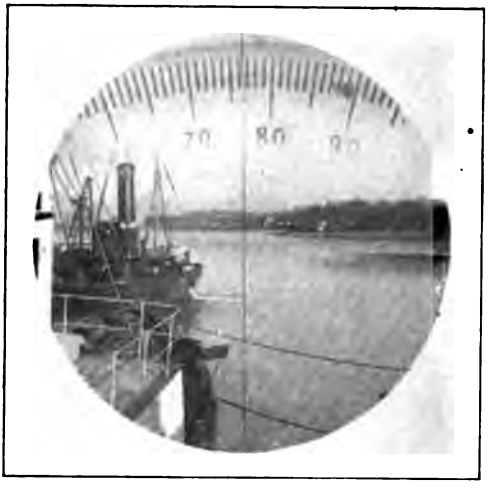

FIG. 10 VIEW TAKEN THROUGH PERISCOPE

the picture is the lower end of one of the periscopes. Behind this is an escape hatch, the ladder to it having been removed to avoid obstructing the view from the camera. In the left lower corner is the ice box, then comes the battery and auxiliary switchboards. In the center of the picture is the closed door leading into the engine room. To the right of the door is the control equipment of the two main motors and on the right are the electric cooking range and galley sink.

26 Fig. 12 gives a good idea of the mass of equipment of a submarine, every part of the space being utilized. The picture is taken from amidships looking forward. In the center of the picture is shown the hand steering wheel. In general the steering

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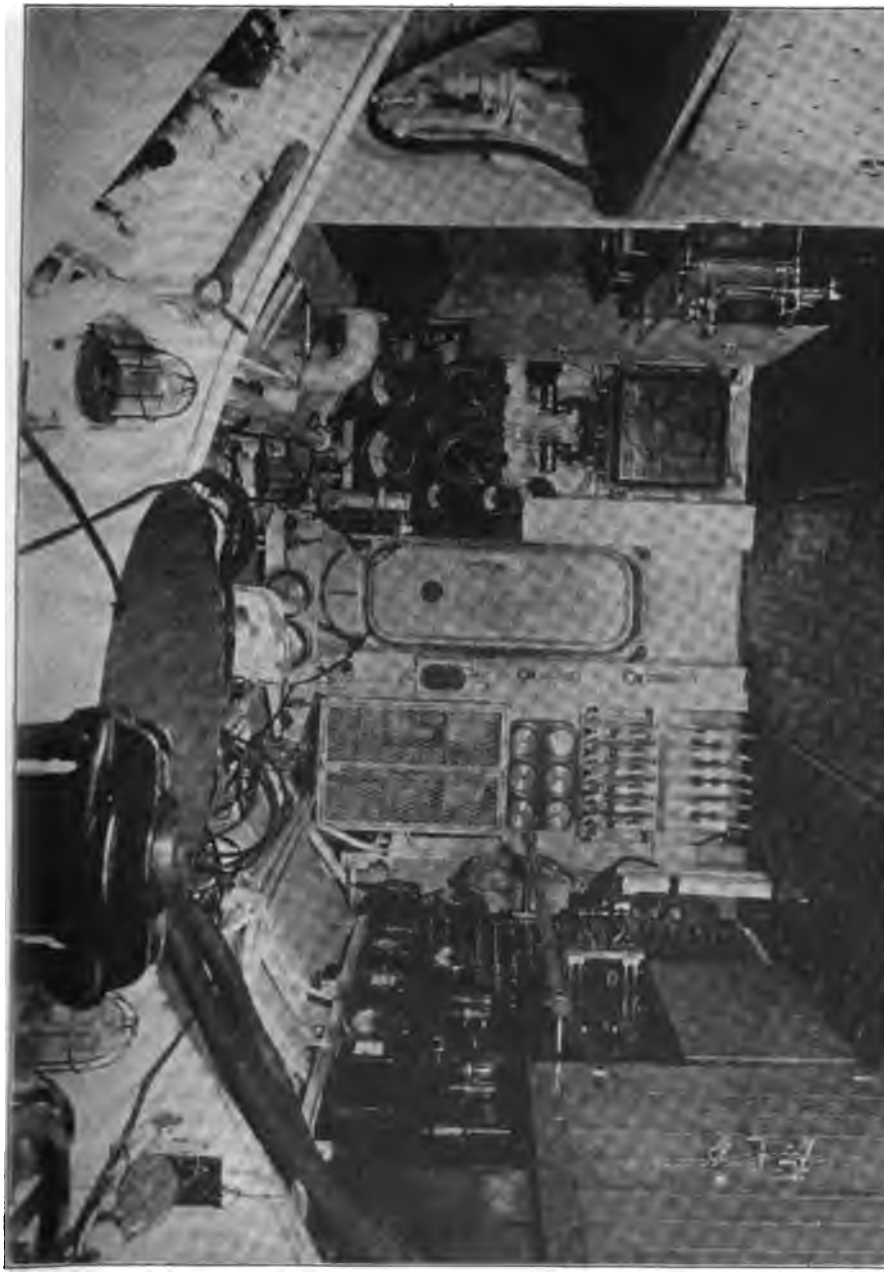

FIG. 11 AFTER END OF CENTRAL OPERATING COMPARTMENT

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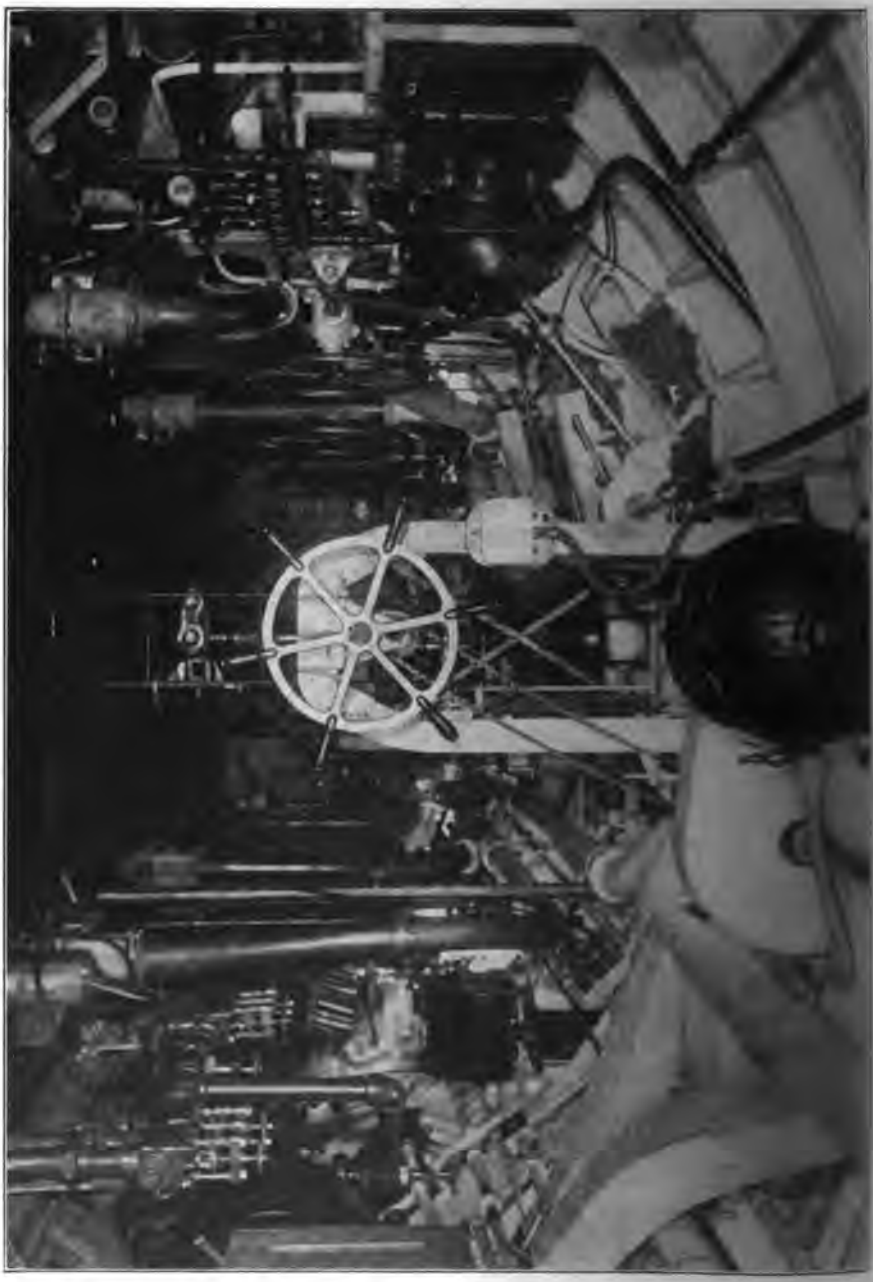

FIG. 13. Fenal Aluminium Lighting Forward

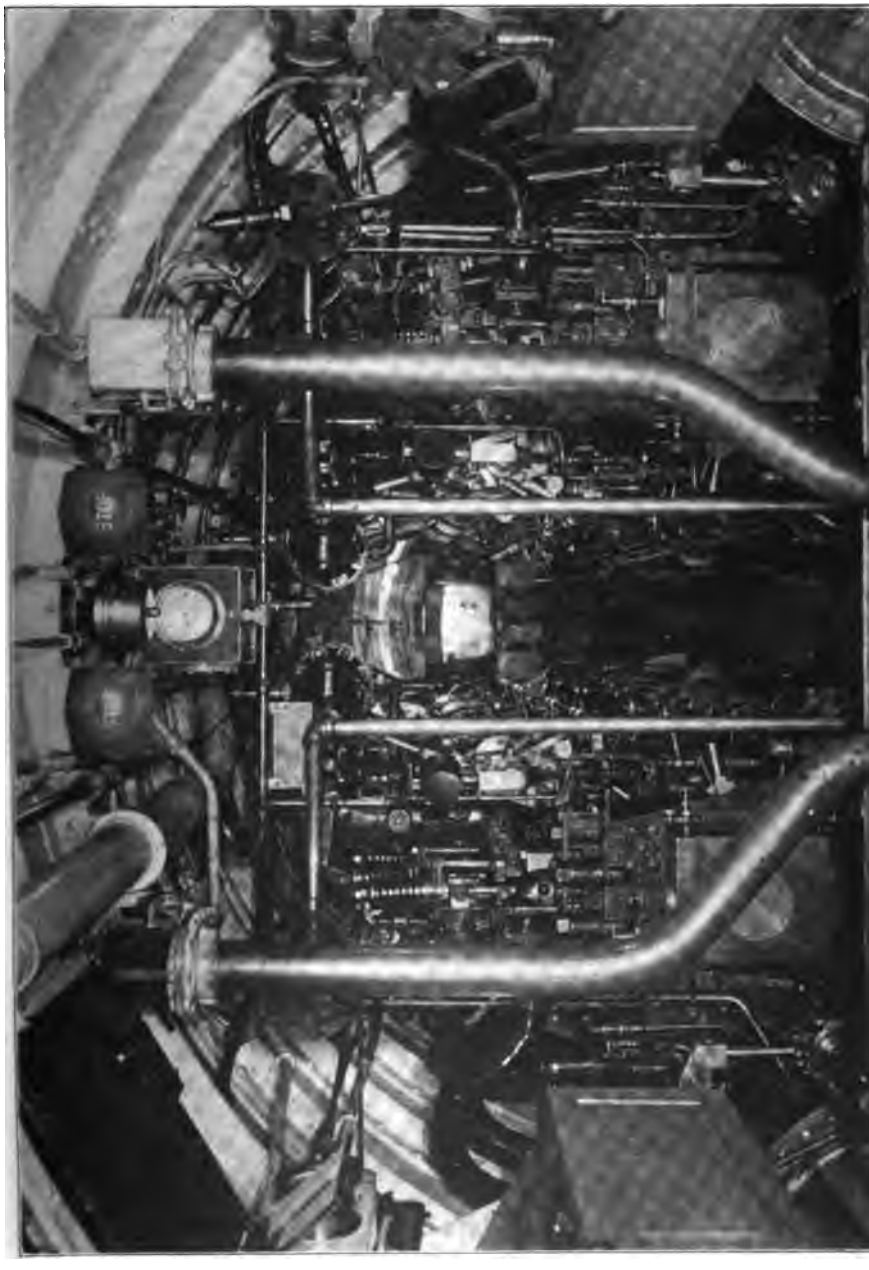

FIG. 13 FROM AMIDSHIPS LOOKING AFT

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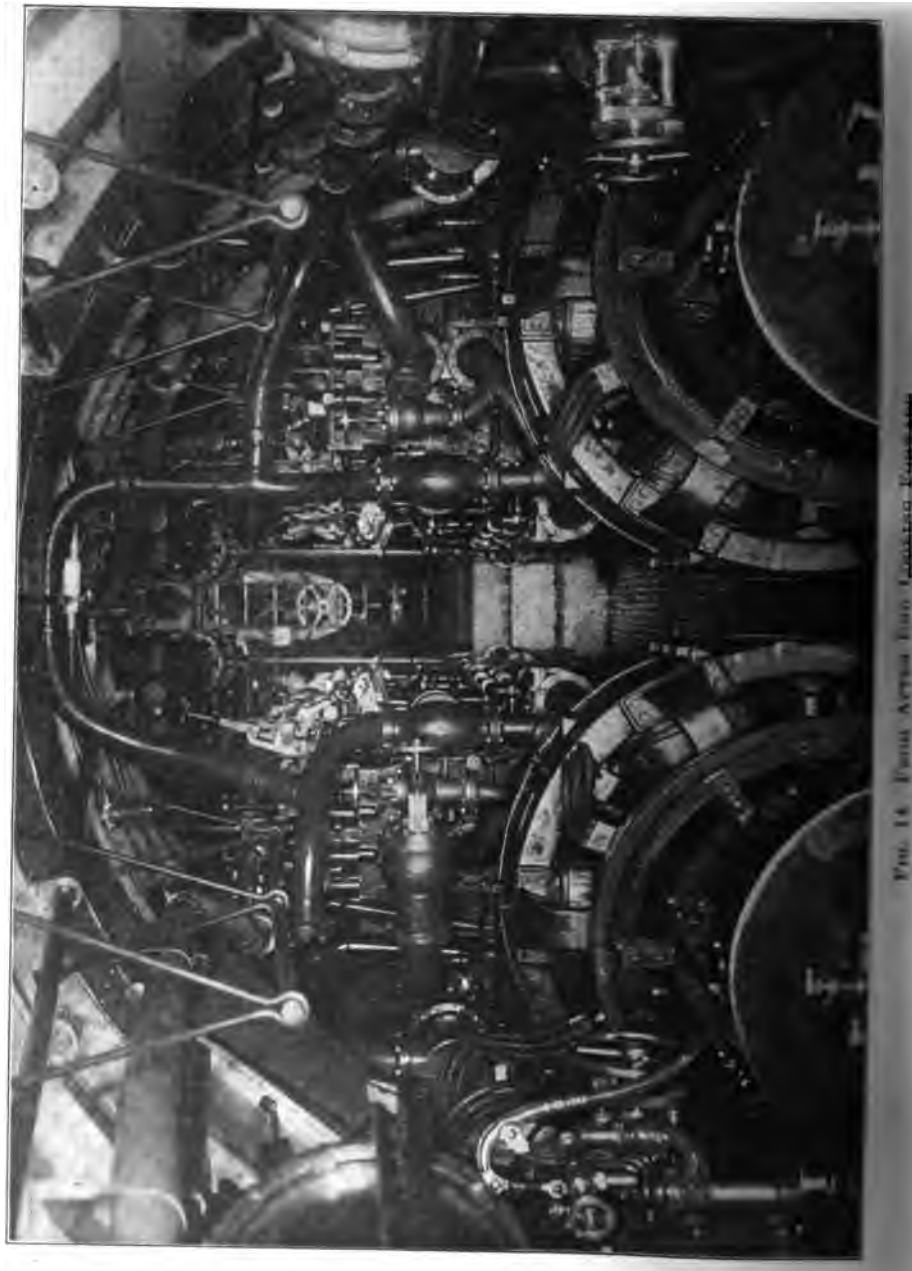

FIG. 14. FIRST ACTION FOR LIGHTING [illegible]

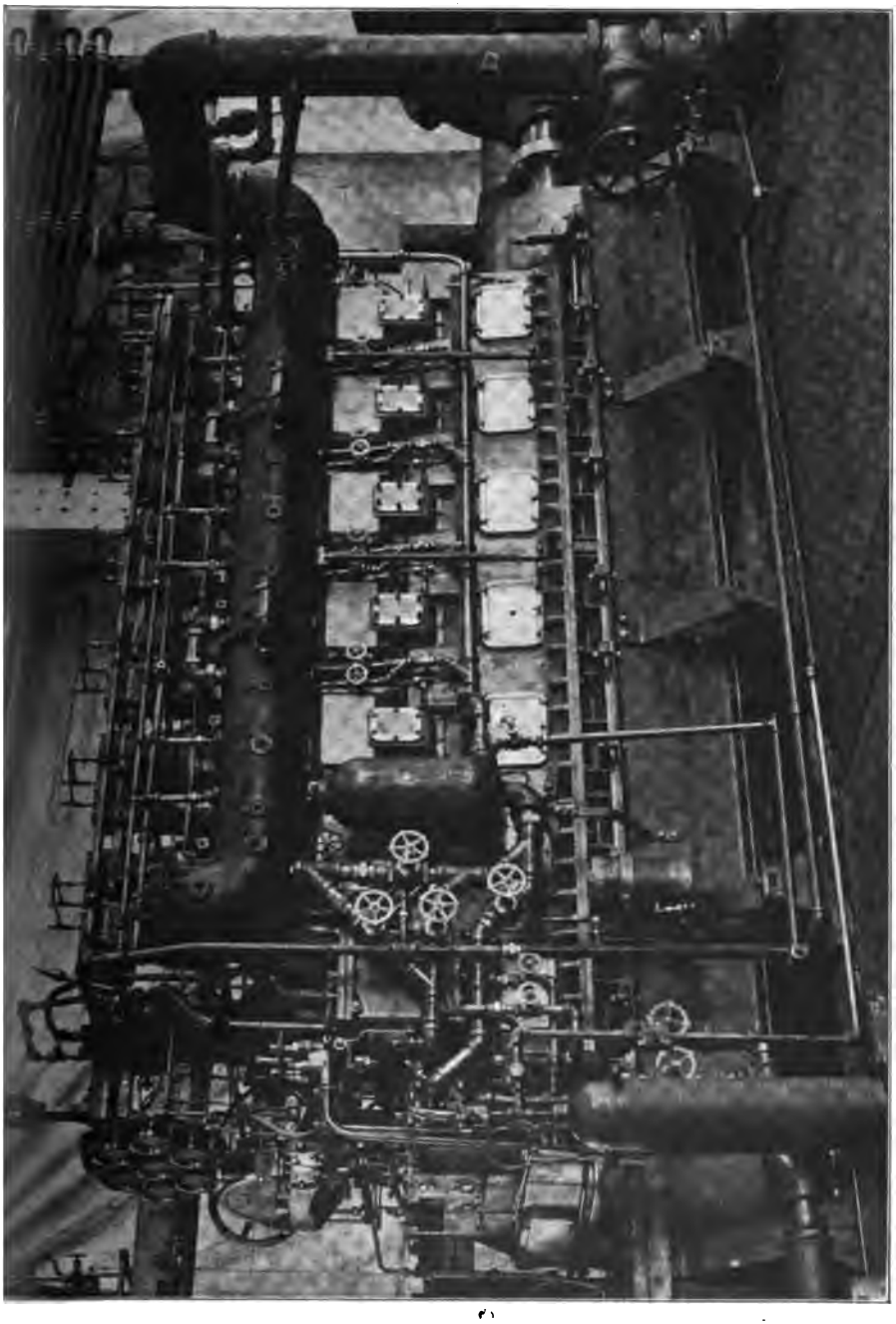

FIG. 15 450-HP. TWO-CYCLE DIESEL ENGINE

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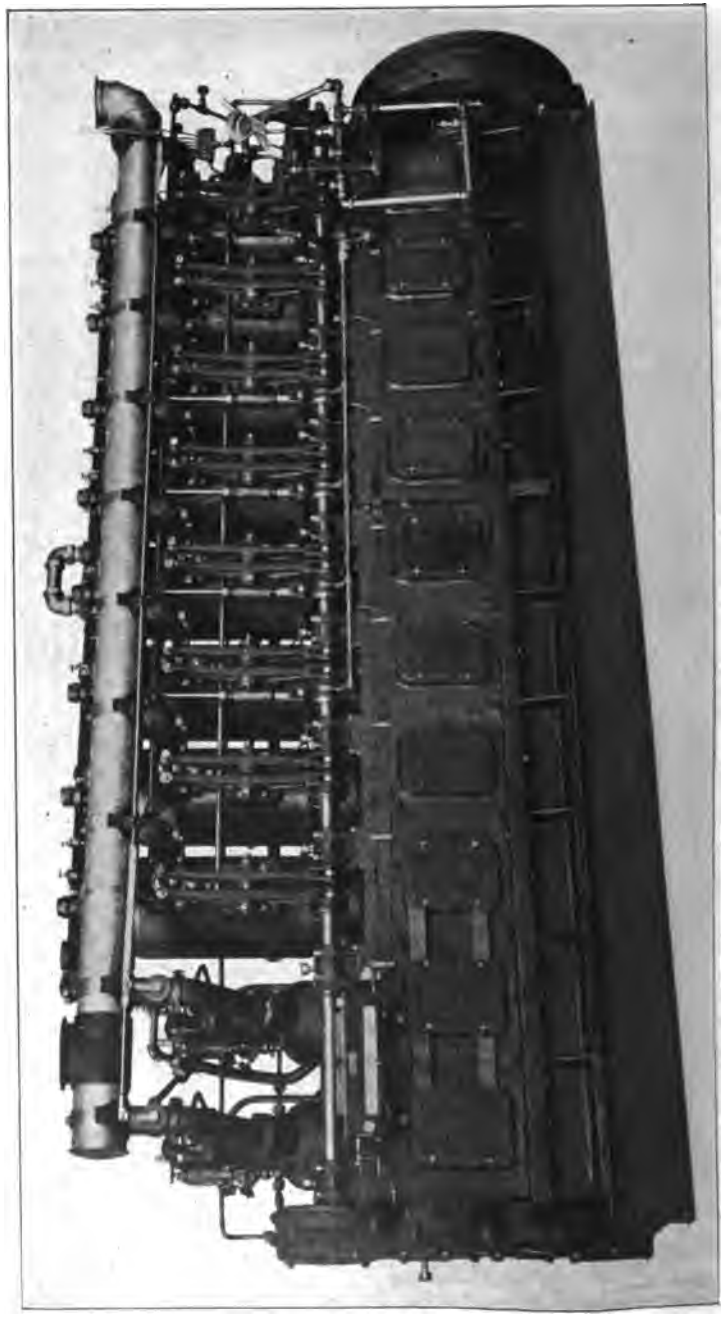

FIG. 16 240-HP. FOUR-CYCLE DIESEL ENGINE

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is done by an electric motor, shown at the top of the picture. On the left is the air manifold, with valves for control of the high-pressure air. These valves connect the air to all the different tanks. By opening the valves to the main ballast tanks, the water may be blown out in a short period of time. On the right is shown the water manifold which connects the different tanks to the adjusting pumps, also the levers of the large Kingston valves. Fig. 13 gives a view looking aft from amidships and showing the main engines, and Fig. 14 from the after end looking forward, showing main motors and engines.

27 One of the two engines for a submarine on the test stand is shown in Fig. 15. For many years the gasoline engine was the best at our disposal, but as gasoline is a bad thing to handle in the confined space of a submarine, we were glad indeed when the Diesel heavy-oil engine became available for this work. The development of these engines was quite advanced in Germany before any such marine engines were built in this country. In order that we might advance as rapidly as possible, all known engines of this type were examined by our engineers, and the conclusion reached that the engine built in Nuremburg was the best then developed. Steps were immediately taken to acquire the rights for this country, and we were thus able to get for our submarines the best engine then developed. Many of these engines were built and are now in operation in our submarines. In the building and operating of these engines we found there were many things we did not like, the principal point being that they were very complicated. In consequence a new engine was designed — illustrated in Fig. 16. This is the type of engine used in many submarines recently built and has stood hard service with wonderfully good results. The change from gasoline to heavy oil has brought out one very interesting characteristic, that is, that with a given quantity of heavy oil, twice the number of horsepower-hours may be obtained as from a like quantity of gasoline. Thus with a boat having a given fuel-tank capacity, double the radius of action is obtained when the change from gasoline to heavy oil is made. Another point is that heavy oil costs about one-fifth as much per gallon as gasoline; thus, for a given number of horsepower-hours the fuel of the Diesel engine costs but one-tenth that for the gasoline engine.

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FIG. 17 STRIPPED FOR DIVING OPERATIONS

FIG. 18 TRIMMED FOR DIVING

FIG. 19 STARTING AHEAD WITH DIVING RUDDER AT ZERO

FIG. 20 STARTING TO DIVE

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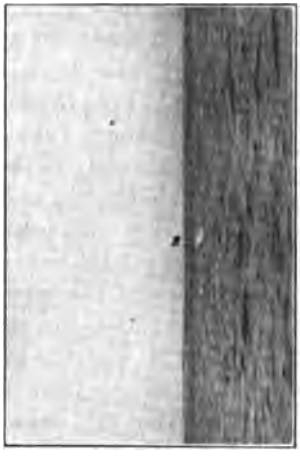

FIG. 22 RUNNING SUBMERGED

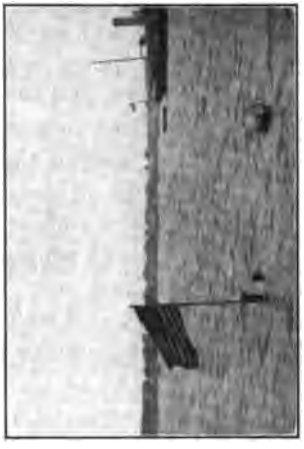

FIG. 23 STATIONARY SUBMERGED

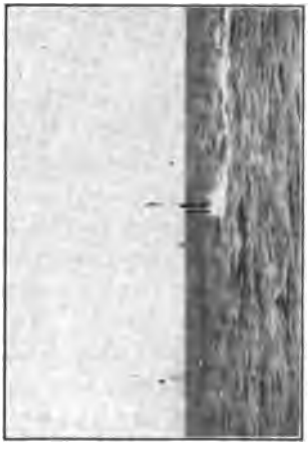

FIG. 21 DIVING

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OPERATION OF SUBMARINES

28 The diving and behavior of the boat submerged is exceedingly interesting, and is shown in Figs. 17 to 23. In Fig. 17 we have the submarine stripped of all deck fittings and ready for submerged running. It takes but a few minutes to take down life lines, etc., close hatches and fill the ballast tanks. Fig. 18 shows the boat thus trimmed down and ready for submerged running. The buoyancy is about 800 lb. and when thus trimmed the boat may be steered down or up with the diving rudders, exactly as the usual steering rudder guides a surface boat. If now the boat is started ahead with diving rudders kept at zero, the boat will rise as shown in Fig. 19. That is, the natural tendency of the boat is always to rise. If now the boat is given a diving rudder, the stern will rise, the bow will go down as shown in Fig. 20 and the boat will slide under. When this photograph was taken the boat was making a quick dive, and the angle of the boat is about five degrees. In general but three-degree angles are used in diving or rising, and for uniform running the boat angle will probably not change one degree. In Fig. 21 we see the boat well under, and, in Fig. 22 she is running at a uniform depth. The actual distance of the boat from the camera when this picture was taken was but 94 yd., a very short distance over water. The control of depth even at high speed submerged is wonderfully accurate, runs being frequently made when for ten minutes at a stretch the depth will not change one foot.

29 If a submarine is resting on the surface and water is admitted to her tanks, she will gradually settle in the water. If care is exercised as the balancing point is reached the adjustment may be made so accurate that another gallon of water admitted to her tanks would cause the boat to sink. This is illustrated in Fig. 23, showing a boat weighing in the neighborhood of 400 tons thus evenly balanced. For the purpose of control of water in the tanks a small rotary pump is used, operated by a reversible electric motor. Thus water may be pumped either into or out of a tank. If when a boat is thus carefully balanced a little water is pumped into her tank, she will start to sink. Suppose after she has settled say to a depth of 40 ft. we pump out a little water. This will check her downward movement, and then she will start to rise. By watching the depth gage, and by careful control of the water by means of the pump, we may hold the boat suspended within a difference of depth of two feet.

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30 In general, after this test that of the automatic blow valve is made. This valve connects the high-pressure-air line with the main ballast tanks, and the control of the valve is by diaphragm in connection with the outside sea water. Thus if the pressure reaches too high a figure, the high-pressure air is automatically turned into the main ballast tanks. These tanks, it will be remembered, are entirely filled with water, whenever any is there, and therefore at such times the main Kingston valves are left open. The turning of the high-pressure air into these tanks is all the operation required to empty the tanks. In the test the automatic blow valve is set to some depth, say 50 ft., and the boat allowed to slowly sink. When this depth is reached the pressure outside operates the valve and some 75 tons of water are quickly blown out of the tanks. The boat immediately starts to rise, and in less than one minute will reach the surface, nearly jumping out of the water from the rapid rise. The automatic blow valve may be set for any depth that may be desired.

31 The subject of rescue of men from a sunken submarine seems to fascinate our inventors, as hardly a week passes but that some one comes forward with the same old method, that of a buoy of such a size that a man may get into it and then rise to the surface. It is not a question of getting a man to the surface — that is easily done, but of keeping him alive when he gets there. In this connection the statement should be made that there is only one cause that will prevent a submarine from coming to the surface, and that is a rupture of her hull. If now the hull is ruptured, the pressure of the outside sea is brought upon the men. In our respiration air is taken into the lungs, the oxygen taken up by the blood is used in the purifying of the blood, and a certain amount of nitrogen is retained in solution. This amount of nitrogen in solution in the blood is small at ordinary pressures, and in any case does no harm, for its quantity is a constant. If now a man is placed under heavy pressure, as would be the case if the hull of a submarine were ruptured say in 200 ft. of water, this pressure of about 100 lb. per sq. in. would cause the blood to absorb many times its normal quantity of nitrogen. This absorption takes place very rapidly and it requires but a few minutes for the blood to become saturated to the point called for by the new pressure. If now a man so placed should enter a can buoy and rise to the outside air, the pressure would be quickly relieved and the excess nitrogen of the blood would be given off all through the system, given off in

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small bubbles which would instantly stop all blood circulation and cause death.

32 This action of the nitrogen is a familiar one to divers and all who are called upon to work under heavy air pressure. Thus it is not a question of the quick application of pressure, but the quick removal of that pressure. As an illustration, a few years ago a Government diver went down some 280 ft. off New London. He took two minutes in going down, spent five minutes on the bottom, and then started for the surface. He came up a little way and then stopped, exercised his arms and legs, thus encouraging activity of the blood in order to work the nitrogen off through his lungs. Then he would come up a little further and repeat the operation. The total time thus taken to reach the surface was one hour and thirty-five minutes, and even then as soon as he was taken out of his diving suit he was put into a recompression chamber so that the pressure might be still more slowly relieved. It will thus be seen how impossible it would be in the excitement of a wreck to go through any such procedure as outlined above.

33 Recent activities of submarines abroad have demonstrated the abilities of the boats, but generally the conditions are quite different from those that would pertain here in case we should be at war with one of the great foreign powers. Then the office of our submarines would be the breaking up of a blockade of our ports, or the preventing of an armed force from making a landing on our shores. Many times in naval maneuvers submarines have successfully attacked battleships, and where sufficient numbers of submarines are employed they may easily prevent a blockade by such ships. An interesting report was given some time ago of the breaking up of an entire expedition of a German army in its attempt to land at the south end of the Gulf of Riga, the work having been done entirely by two small submarines. If the report is true it shows wonderfully effective work by the submarines.

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No. 1623

AN ACCOUNT OF THE ENGINEERING WORK OF E. D. LEAVITT

By F. W. Dean, Boston, Mass.
Member of the Society

E. D. LEAVITT received his education in the public schools in Lowell, Mass., learned the machinist's trade in the Lowell Machine Shop, was assistant foreman at Harrison Loring's works at South Boston, was chief draftsman at the works of Thurston, Gardner & Co., at Providence, entered the Navy in 1861, and resigned therefrom in 1867. At this time he began the office practice of mechanical engineering, and on account of the times and his ability he achieved great success, not, however, without some discouragements.

2 I have understood that his first steam engine was designed for Crozer's cotton mill, in Chester, Pa., and built by I. P. Morris & Co., Philadelphia. This was a simple horizontal engine with a steam chest as long and wide as the cylinder. The chest contained a very large main valve worked by an eccentric and having a cut-off valve on its back at each end worked by a cam. The steam exhausted into the main valve which was hollow, and from this passed out through a special exhaust port. The main valve, being in a chest of live steam and having exhaust steam within, formed a condenser to some extent, and to persons who knew of Mr. Leavitt's great efforts in general to secure economy this was a subject of comment. Later he used the same design for the Brooklyn Bridge engines and for those of the El Callao Mining Co. of Venezuela. He appeared to be attached to this design and spoke of it as his cheap engine, but never mentioned its obvious defect.

3 Mr. Leavitt was firmly of the opinion that the best valve for steam engines was the gridiron (Fig. 1) and he always used it except in the few cases mentioned above. The Plymouth Cordage Co's. en-

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gine which was built by Harrison Loring in 1868–9 was the first engine embodying the regular Leavitt features of four gridiron valves operated by cams. This was a vertical simple condensing beam engine having a steamboat beam with a cast-iron center and wrought-iron strap, the beam being above the cylinder and crankshaft. After being in operation a great many years the cams, which were

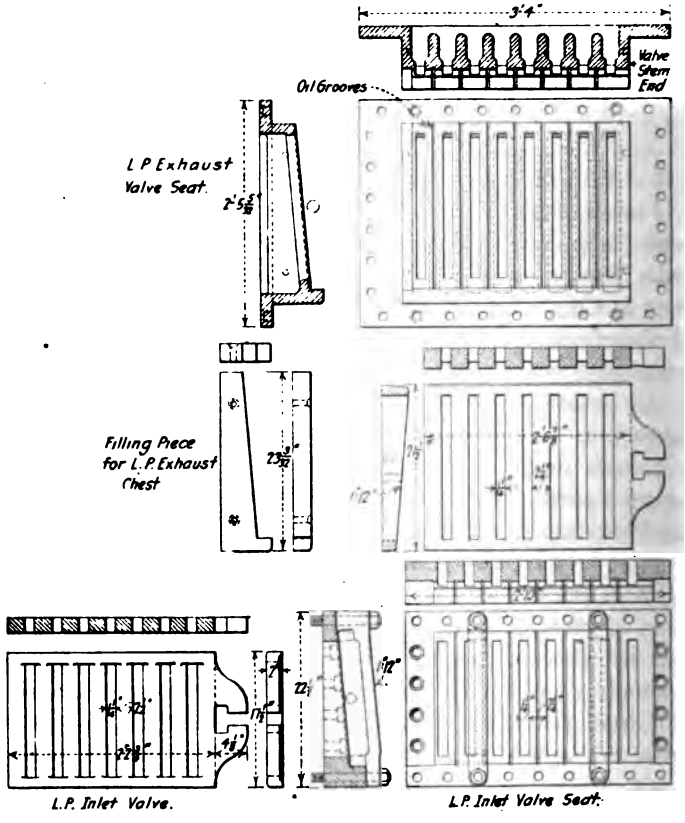

FIG. 1 VALVES AND SEATS

of the side-groove type, became very noisy and the cylinder was replaced by a George H. Corliss cylinder and valve gear.

4 It was said that up to the time of removing the Leavitt cylinder the valves were tight and the indicator diagrams of the best form.

5 Mr. Leavitt claimed that the gridiron valve was the only one that would remain tight indefinitely. The reason for this was that

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ERASMUS DARWIN LEAVITT, ONE OF THE ORIGINAL MEMBERS OF THE SOCIETY. VICE-PRESIDENT, 1881–1882. PRESIDENT, 1883. HONORARY MEMBER, 1915. DIED MARCH 11, 1916

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it has a great deal of wearing surface and no tendency to cock over and press more on one edge than the other, and that when operated by cams has a constant travel, except, of course, the cut-off valves at early cut-offs.

6 Mr. Leavitt used cams because they enabled him to secure exact and unchangeable motion to the valves.

7 The automatic cut-off feature was obtained by placing a cam on a hollow piece of shaft or sleeve through which the camshaft passed, and by suitable connection with the governor the cut-off cam could be advanced or retarded. This was accomplished by having a spiral slot cut in the camshaft and a straight one in the sleeve, a key made to fit both and moved by a sliding collar, which in turn was moved by the governor.

8 It is obvious that the governor moved the valve and therefore had to be large and powerful. For good governing this was not satisfactory, except for pumping engines, which ran slowly, and finally the governing apparatus was changed to that having a small high-speed governor whose function was to operate a balanced piston valve which admitted and exhausted water or oil under pressure to and from a hydraulic plunger and this moved the cut-off collar. Thus the governor had no resistance to overcome except friction, and could be made as sensitive as desired. After the first trial of this governor it was always used.

9 Mr. Leavitt's fame began with the installation of the Lynn, Mass., pumping engine built by I. P. Morris & Co., which made an advance in economy over anything which preceded it. Its economical performance was based upon coal consumed, and upon its trial in December, 1873, it gave a duty of 103,923,215 ft-lb. per 100 lb. of picked Lackawanna anthracite coal based upon water discharged over a weir. While the feedwater was weighed and indicator diagrams taken, no evaporative rate for the boilers nor rate of steam consumption for the engine were given in the report.

10 The Lynn engine was soon followed by the Lawrence engines, also built by I. P. Morris & Co., which were tested for duty based upon 100 lb. of coal consumed and water discharged as determined by weir measurement. The test was made on May 2 to 6, 1876, and the duty was 96,186,979 ft-lb. per 100 lb. of Cumberland coal. The boilers were of an excellent design of the locomotive type and ought to have given a very high evaporation if properly fired. They only evaporated 8.27 lb. of water and 8.69 lb. on different tests per pound of coal from feed at 100 deg. fahr. and pressure at 89 lb. This was

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attributed to poor coal, but must have been due to poor firing. In those days calorimeter tests of coal and analyses of escaping gases were seldom made. Here again, while feedwater was weighed and indicator diagrams were taken, the steam rate of the engine was not worked out.

11 Fortunately Park Benjamin's Scientific Expert Office tested one of the Lawrence engines in 1879 after the engine was over three years old. The report does not state when the test was made, but it was evidently in July, 1879, as the report is dated July 30 of that year. The principal data and results were as follows:

Date	July, 1879
Duration of test	15.1 hr.
Kind of coal used	Cumberland bituminous
Diameter of high-pressure cylinder, in	18
Diameter of low-pressure cylinder, in	38
Diameter of plunger, in	18.5
Stroke of steam pistons and plunger, ft	8
Diameter of flywheel, ft	30
Clearance of high-pressure cylinder, per cent	top, 2.56; bottom, 2.31
Clearance of low-pressure cylinder, per cent	top, 1.54; bottom, 1.82
Steam pressure above atmosphere, lb	89.5
Vacuum, in	27.4
Revolutions per minute, average	13.62
Discharge of pump in 24 hr. by plunger displacement, gal	4,401,272
Duty per 100 lb. of coal consumed, based upon plunger displacement, ft-lb.	111,548,925
Temperature of feedwater, deg. fahr	119
Temperature of escaping gases, deg. fahr	358
Coal consumption per sq. ft. of grate per hr., lb	8.38
Actual evaporation per pound of coal, lb	10.13
Equivalent evaporation from and at 212 deg., lb	11.49
Equivalent evaporation per pound of combustible from and at 212 deg., lb.	12.24
Coal used per indicated horsepower-hour, lb	1.63
Feedwater used per indicated horsepower-hour, lb	16.48
Feedwater used per hour, lb	2437
Condensation in high-pressure cylinder jacket per hour, lb	118
Condensation in low-pressure cylinder jacket per hour, lb	160

12 In this table we have means of judging of the economical performance of both boiler and engine. The former was among the best and the latter was probably as good as that of any steam engine up to that time. There appears to have been no determination made of the moisture in the coal or in the steam.

13 The perspective drawing given in Fig. 2 (taken from the Park Benjamin report) gives a good idea of the Lawrence engines, and serves the same purpose for the Lynn engine, there being one engine in the latter case.

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THE BOSTON SEWAGE ENGINES

14 When the city of Boston undertook to dispose of its sewage by discharging it into the ocean south of the harbor limits, it became necessary to raise it about 40 ft. near the north shore of Dorchester Bay. Mr. Leavitt designed two vertical compound flywheel engines for this purpose, which are shown in Fig. 3. These were built by the Quintard Iron Works, New York, and were vertical inverted compound flywheel beam engines of the following general dimensions:

Diameter of high-pressure cylinder, in.	25½
Diameter of low-pressure cylinder, in.	52
Diameter of each of the two plungers, ft.	4
Stroke of each piston and plunger, ft.	9
Number of revolutions per minute, nominal	10¾
Capacity in 24 hours, nominal, gal.	25,000,000

15 The cylinders were steam-jacketed and there were tubular reheaters between the high- and low-pressure cylinders, one being between the upper ends of the cylinders and the other between the lower ends.

16 In 1885 one of the engines and its twin-furnace locomotive-type boiler were tested by Dexter Brackett with the following results:

Dates of trials, 1885	Mar. 24–25	May 1–2
Duration	24 h. 43 m.	24 h. 3½ m.
Revolutions per minute, average	13.17	13.42
Total lift, ft.	37.80	42.43
Total dry coal consumed, lb.	8307	9478
Duty per 100 lb. dry coal, ft-lb.	125,450,000	122,400,000
Mean boiler pressure, lb. per sq. in.	99.4	98.6
Mean vacuum in condenser, in.	28.1	28.0
Total plunger displacement, gal.	33,038,000	32,778,000
Total discharge by weir, gal.	30,224,000	31,256,000
Average slip, per cent	8.5	4.6
Approximate indicated horsepower	251.5	290.2
Plunger horsepower, no allowance for slip	212.9	243.5
Mechanical efficiency, per cent	84.66	83.90
Approximate coal used per i.hp-hr., lb.	1.33	1.35
Approximate steam used per i.hp-hr., lb.	13.89	14.09

RESULTS OF BOILER TRIALS

(Twin-furnace locomotive type)

Dates of trials, 1885	Mar. 24–25	May 1–2
Duration	24 h. 51 m.	24 h. 9½ m.
Grate area, sq. ft.	45.5	45.5

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Water-heating surface, sq. ft.	1826	1826
Heating surface of flue economizer, sq. ft.	934	934
Ratio of boiler heating surface to grate area	40 to 1	40 to 1
Steam pressure, lb. per sq. in.	99.4	98.6

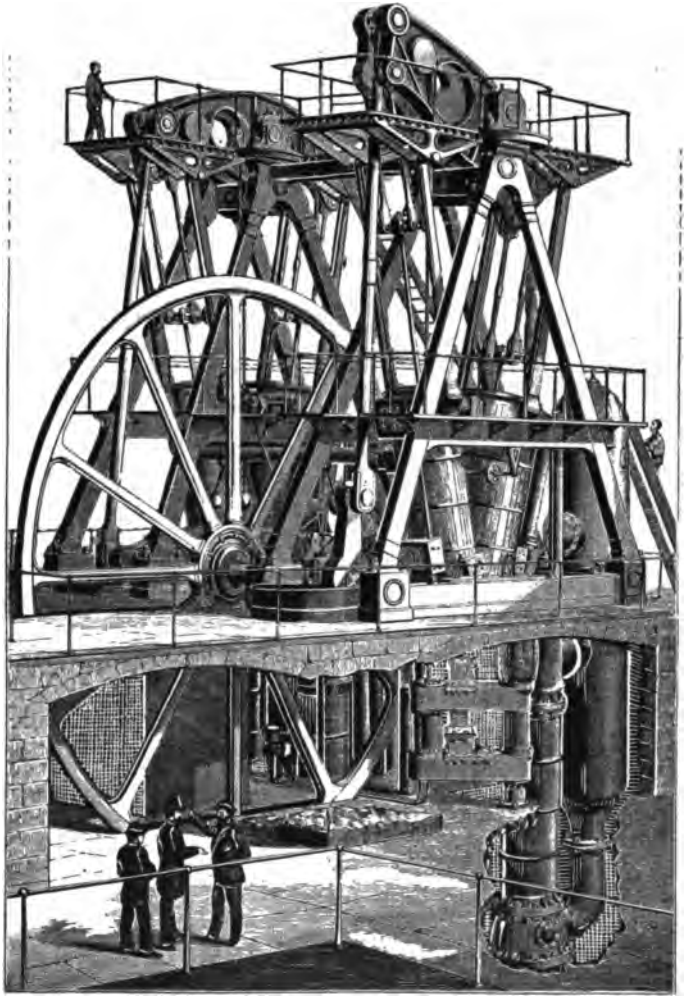

FIG. 2 THE LAWRENCE PUMPING ENGINES

Temperature of escaping gases from boiler, deg. fahr.		439
Temperature of escaping gases from economizer, deg. fahr.	183.5	194.2
Temperature of feedwater entering economizer, deg. fahr.	96.5	120.7

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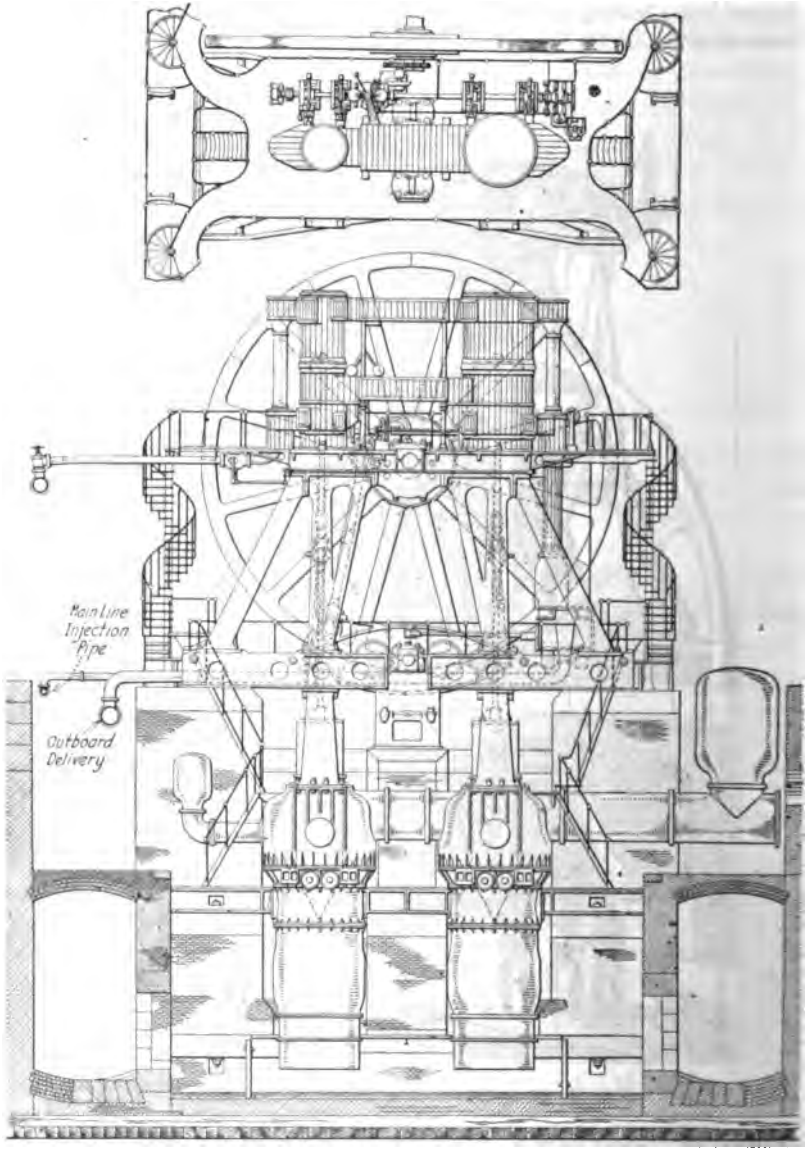

FIG. 3 BOSTON SEWAGE ENGINE

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Temperature of feedwater entering boiler, deg. fahr..	145.1	164.1
Temperature of feedwater entering building, deg. fahr.	38	46
Dry coal consumed, lb.....	8307	9478
Dry refuse, lb.....	432	497
Water weighed into boiler, lb.....	86,783	98,780
Water evaporated per lb. of dry coal, lb.....	10.45	10.42
Water evaporated from and at 212 deg. by boiler per lb. of dry coal, lb.....	11.60	11.35
Water evaporated from and at 212 deg. by boiler and economizer per lb. of dry coal, lb.....	11.60	11.83
Water evaporated from and at 212 deg. by boiler per pound of combustible, lb.....	12.23	11.98
Water evaporated from and at 212 deg. by boiler and economizer per lb. of combustible, lb.....	12.78	12.48
Dry coal consumed per sq. ft. of grate per hr., lb....	7.35	8.62
Water evaporated by boiler per hr. per sq. ft. of heating surface from and at 212 deg., lb.....	2.12	2.44

17 In 1889 he designed a larger triple-expansion engine for the same place.

THE LOUISVILLE PUMPING ENGINE

18 The next pumping engine of Mr. Leavitt's design to attract attention was the Louisville engine, Fig. 4, built by the I. P. Morris Co.[1] and it was the first to be thoroughly tested. The test was conducted by Dexter Brackett and F. W. Dean and lasted 144 hr. 10 min. without stopping.

19 The engine was arranged similar to the Boston sewage engines, but had the flywheel shaft near the floor level and at one end of the bedplate instead of being elevated and between or just below the lower ends of the cylinders. The reheaters were of the same type.

20 The following are the general results of the test:

Diameter of high-pressure cylinder (hot), in.....	22.21
Diameter of low-pressure cylinder (hot), in.....	54.13
Diameter of high-pressure piston rod, in.....	5.50
Diameter of low-pressure piston rod, in.....	6.00
Stroke of each piston, ft.....	10
Mean clearance volume of high-pressure cylinder, per cent.....	1.585
Mean clearance volume of low-pressure cylinder, per cent.....	1.530
Diameter of each differential plunger, in.....	34 and 24$\frac{1}{16}$
Stroke of each differential plunger, ft.....	7
Diameter of flywheel, ft.....	36
Duration of trial.....	144 hr. 10 min.
Revolutions per minute, average.....	18.574

[1] Originally I. P. Morris & Co., but later changed to I. P. Morris Co.

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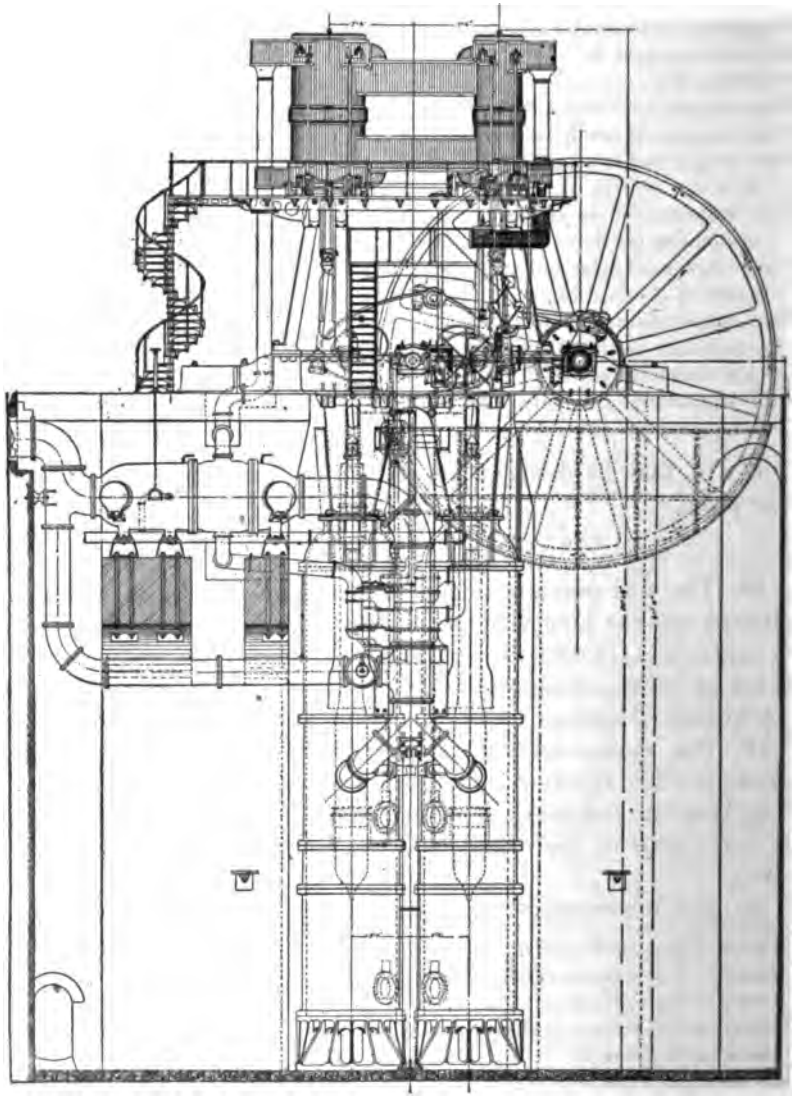

FIG. 4 LOUISVILLE, KY., PUMPING ENGINE

Average steam pressure at the engine, lb. per sq. in.	137
Back pressure on low-pressure piston, lb. per sq. in.	0.95
Total head, ft.	193.35
Total dry steam used by engine in cylinders and jackets, lb.	1,127,533
Dry steam used per i.hp. per hour, including jacket steam, lb.	12.156

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Horsepower of high-pressure cylinder	279.00
Horsepower of low-pressure cylinder	364.40
Horsepower of both cylinders	643.40
Horsepower of plungers	599.10
Mechanical efficiency of engine, per cent	93.12
Duty per 1000 lb. of dry steam by plunger work, ft-lb	150,838,000
Duty per 1,000,000 B.t.u. by plunger work, ft-lb	151,672,000
Avg. capacity of engine in 24 hr. by weir, U. S. gal	16,489,420
Avg. capacity of engine in 24 hr. by plungers, U. S. gal	17,681,350
Average slip of plungers, per cent	6.74

THE WASHINGTON MILLS ENGINES

21 These are the only Leavitt power engines that have ever been thoroughly tested as far as I know. They were put in under a guarantee and tested by John T. Henthorn and E. D. Leavitt, Mr. Leavitt being represented by A. M. Mattice. They were built by the Dickson Mfg. Co., Scranton, Pa., and were a pair of 30-in. by 60-in. steam-jacketed horizontal non-condensing engines running at 60 r.p.m. and driving a 30-ft. wheel grooved for thirty $1\frac{3}{4}$-in. ropes. The boiler pressure was 135 lb. and the back pressure on the pistons about 8 lb. These engines are similar to the Calumet and Hecla 40-in. by 60-in. engine shown in Fig. 5. The following are the general results:

Duration of test (June 12–19, 1890)	One week, mill hours
Running time	61 hr. 41 min.
Average steam pressure at engines, lb. per sq. in.	132.2
Average revolutions per minute	58.82
Average back pressure, lb. per sq. in.	7.98
Average indicated horsepower, both engines	1199.2
Net moist steam used by engines (including jackets) per i.hp. per hour, lb.	23.16
Per cent of steam used by jackets	3.05

The test was made after the engines had been in operation about three years.

DETAILS OF ENGINE DESIGN

22 *Cams.* In the early Leavitt engines the cams were made with grooves in the side and the throws were inserted hardened steel. The high-pressure cut-off cam, although it appeared to be grooved, was not in fact. It consisted of two cams, one recessed and overhanging the other. The opening cam was secured to the camshaft and the cut-off cam to the hollow shaft which was controlled by the governor. The rolls which were actuated by the cams were on pins overhung from rockers.

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23 A cut-off cam for the Calumet and Hecla Pumping Engine No. 2 is shown in Fig. 6. This was one of the early pumping engines.

24 When the hoisting engine Superior was built, having cylinders 40 in. and 70 in. by 6 ft., grooved cams were used. The camshaft was located near the floor level, and as the engine was vertical

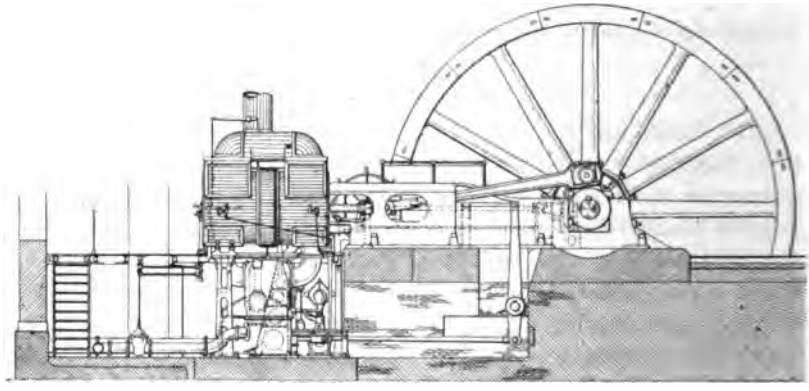

FIG. 5 40-IN. × 60-IN. ENGINE

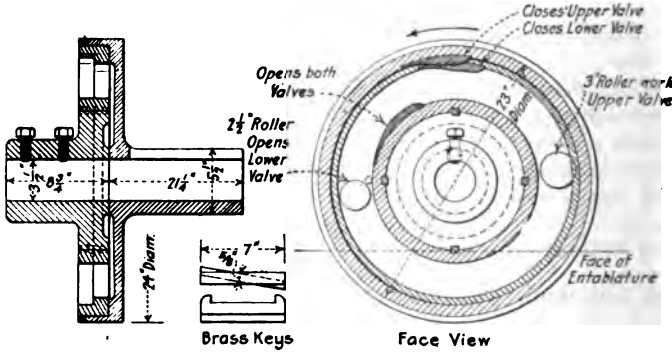

FIG. 6 INLET AND CUT-OFF CAMS

and inverted, the valve rods were very long and heavy. It was intended to run the engine at 60 r.p.m., but the gear would not operate satisfactorily, I have understood, at over 35 r.p.m. The noise was so great at higher speeds that conversation could not be carried on nearby without shouting at close range, and breakages of the cut-off cams and levers occurred. It is a curious fact that Mr. Leavitt was so anxious to have quick cut-offs that he often made cam throws

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too steep for quiet, and sometimes safe, working. The original high-pressure cut-off mechanism of the Superior had a special lever mechanism to accomplish quick valve motion, and this caused part of the trouble. The outcome of the Superior's trouble was that a new valve gear was designed which was light and possessed small inertia stresses, and here Mr. Leavitt's great ability and originality came to the rescue and brought forth the so-called "outside cam" and "wrist-motion rocker." The type of cam is shown in Fig. 7.

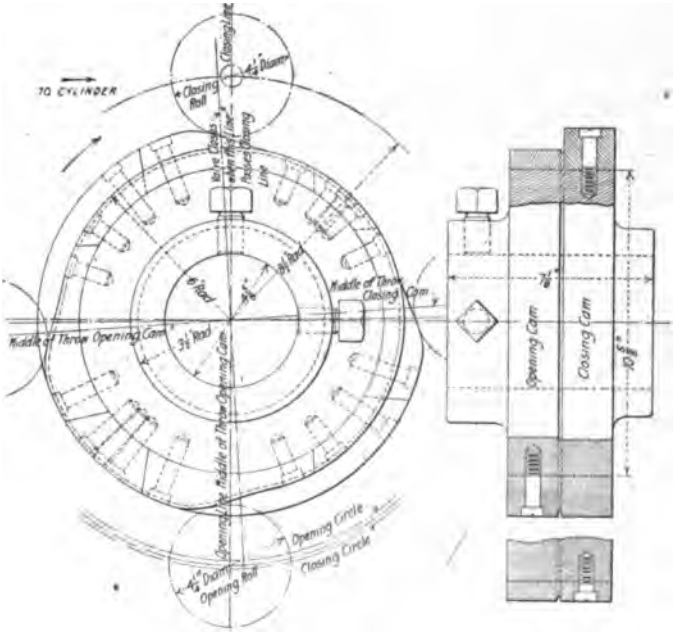

FIG. 7 OUTSIDE CAM

25 In the case of the Superior the camshaft was raised to a level with the middle of the cylinders and was supported, together with the valve gear, by means of brackets attached to the valve-chest bonnets. The valve rockers for the lower valves extended downward, and for the upper valves upward, from the camshaft.

26 The outside cams had rolls on opposite sides rotating on pins in forked rockers so that there were no overhung pins. The pair of rockers of one cam were connected together by links and the throws of the cams were so formed that both rolls always touched the

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cams. The motion was therefore definite and positive. Nothing could well surpass this valve gear in durability, quiet and freedom from repairs. The Superior was started with the new valve gear in the latter part of 1883, and has been running ever since, from 20 hours to 24 hours per day, with the utmost satisfaction.

27 Fig. 8 shows the Superior with the new valve gear, while the paper by Mr. Leavitt on this engine in Vol. 2 of Transactions (facing p. 120) shows it with the original gear.

28 *Cylinders.* The Leavitt cylinders were always steam-jacketed and had the jackets cast on. Mr. Leavitt always feared leakage with cylinders having liners. The jacket was cast with an opening all around the center and this was covered with a copper ring with one corrugation. The ring was secured by two rows of tap bolts on each side. The division of the jacket wall in this way was the result of some serious disasters. The jackets of the Lynn and Lawrence pumping engines were cast without the division and straight, with the result that one or more of them cracked and had to be replaced. A cylinder of a steam stamp at the Calumet and Hecla mine made without provision for jacket expansion broke and went through the roof of the building.

29 The steam chests of the cylinders were always cast on, and sometimes the crank-end head was cast on, and sometimes it was separate. Fig. 9 shows a typical cylinder. Some cylinders were serrated in order to provide more surface for contact with steam and thus render jacket action more active. This was a feature not always used, and was borrowed from the practice of a well-known Belgian engineer.

30 *Valves and Valve Seats.* The valves were rectangular plates with one end formed to receive T-ended valve stems. The ports were slotted. The seats were secured to the cylinder by means of studs, and the surfaces of contact between the cylinder and seat were scraped to continuous contact. The bridges between the ports of the seats were each provided with an oil groove. There were two yokes secured to the seats for preventing the valves from leaving the seats too far. In vertical cylinders the seats were somewhat inclined so that the valves would tend to rest against them.

31 In order to fill up all unoccupied spaces blocks were screwed in or cast on to reduce the clearance volume.

32 In designs made since about 1888, the clearance volume was still further reduced by casting V-shaped forms on the cylinder ports under the bridges of the valve seats. This added to the condensing

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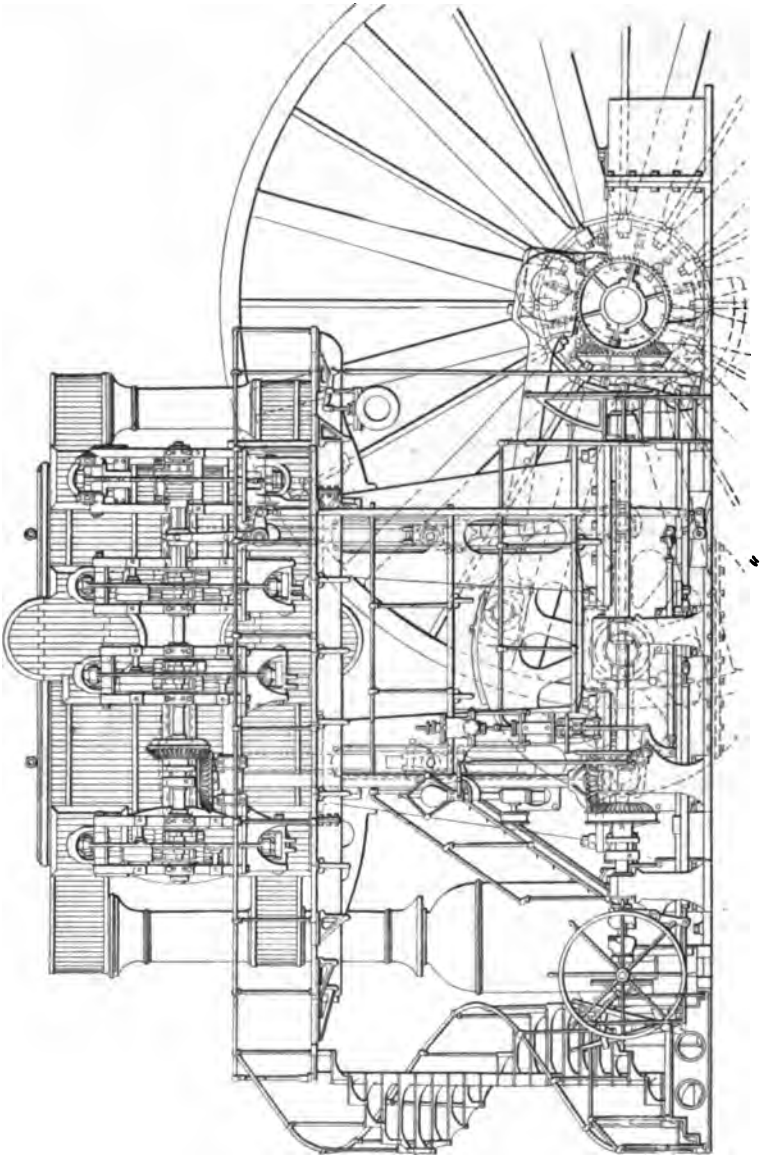

FIG. 8 HOISTING AND COMPRESSOR ENGINE *Superior*

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surface of the clearance, and in fact all other devices for diminishing clearance did this also, and I have often thought that whatever may have been gained by reducing clearance was lost by the increase in surface. All Leavitt engines made an indicator diagram with a long drop in the compression line. The compression would go on for a time and then there would be a collapse which would not be recovered. I think that this was caused by condensation in the clearance, which in turn was caused by the great amount of surface in the valve-seat ports and other parts.

33 There was always means of operating the valves by hand, and this involved a handwheel something like the steering wheel of

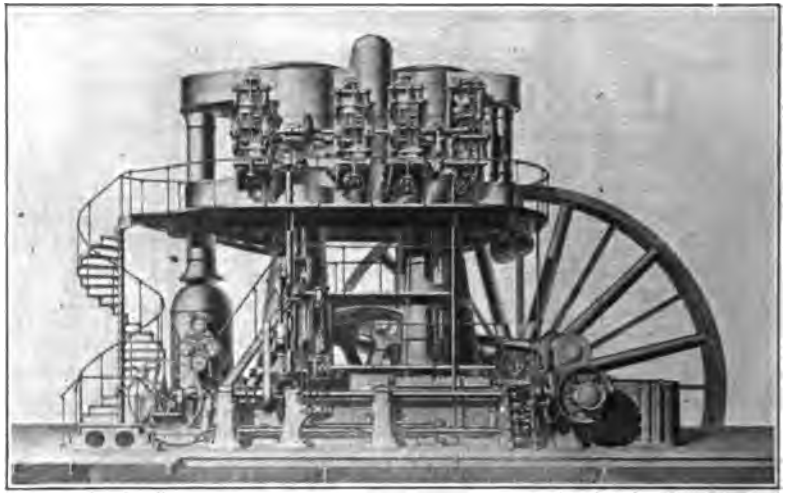

FIG. 8*a* ENGINE *Superior*

a steamboat except that it was of steel. There were two clutches moved by a lever, one of which engaged the camshaft with a driving shaft and the other engaged it with the handwheel. One of course was engaged when the other was disengaged. The operation of starting consisted chiefly in placing the valves in the proper position, opening the throttle and throwing the clutches at the proper time. The skill required to do this was easily acquired.

THE LEAVITT BEAM ENGINE

34 Mr. Leavitt was very fond of the inverted beam engine for the reasons that it made a very low engine and was long and stable

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in the direction of motion of the parts, and cheapened the building by making it lower. The beam was generally made of air-furnace gun iron, but later of steel castings. The weights of the beams and reciprocating parts were very great and they all moved in the same plane, but no trouble came from this in practice.

35 The usual place for crossheads was above the beam, but they have been placed below (see Fig. 16), and in this case the links from the crossheads extended upward to the beam pins. The beams were generally made in two "flitches" (to use Mr. Leavitt's word), but sometimes in a single piece. The connecting-rod pin sometimes was overhung from the beam, but oftener was between the flitches.

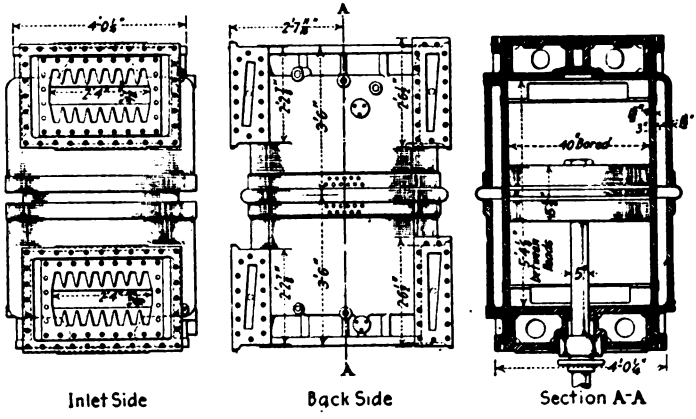

FIG. 9 LEAVITT CYLINDER

36 In compound engines the high-pressure cylinder was above one end of the beam and the low-pressure cylinder above the other, but in 1886 Mr. Leavitt began the design of triple-expansion engines, which he arranged by having the high and intermediate cylinders above one end of the beam and the low-pressure cylinder above the other. The high and intermediate pistons had coincident motions. The steam pressure used for compound engines was 135 lb. and for triple-expansion engines 185 lb.

37 Reheaters were used in each case, and it may here be remarked that Mr. Leavitt had great difficulty in making the reheater tubes tight in the tube plates.

38 In some of the later triple-expansion or three-cylinder compound engines three beams were used and each piston was connected to one end of each beam, and there were three connecting rods and

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three cranks 120 deg. apart. These were certainly beautiful pieces of mechanism and operated to perfection. The first such engine was the Riedler pumping engine of the Boston Water Works, built in 1894 and shown in Figs. 10 and 11.

39 The engine at the Bethlehem Steel Co. designed by Mr. Leavitt for pumping water for the forging press and built by the I. P. Morris Co., is another example of this arrangement, and there

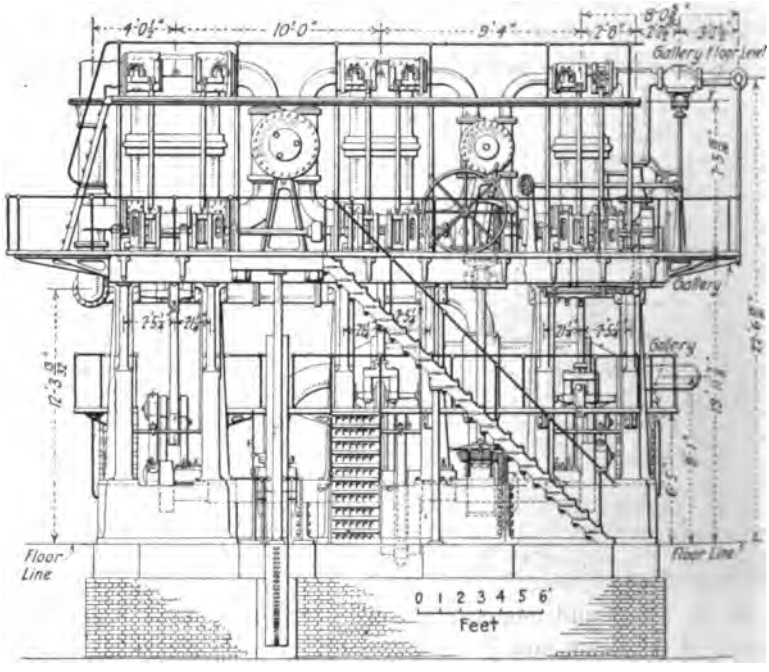

FIG. 10 RIEDLER PUMPING ENGINE, BOSTON WATER WORKS

are three of them driving electric generators at the stamp mill of the Calumet and Hecla Mining Company, as well as several hoisting engines of this type. In the stamp-mill engines although gridiron valves were used, they were not operated by cams. They were opened by eccentric rods and were provided with latches and dash-pots as in Corliss gears. This feature of the valve gear was caused by the engines having been built for a reversing hoisting gear, and the valves could be better controlled by a reversing link when so made than if reciprocating cams were used as on the engines Minong

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and Siscowit. The engines with the latches and dashpots have each one 24-in. high-pressure cylinder and two 40-in. low-pressure cylinders and run beautifully at 107 r.p.m. When the engines were used for driving electric generators the reversing links were removed. (Fig. 26.)

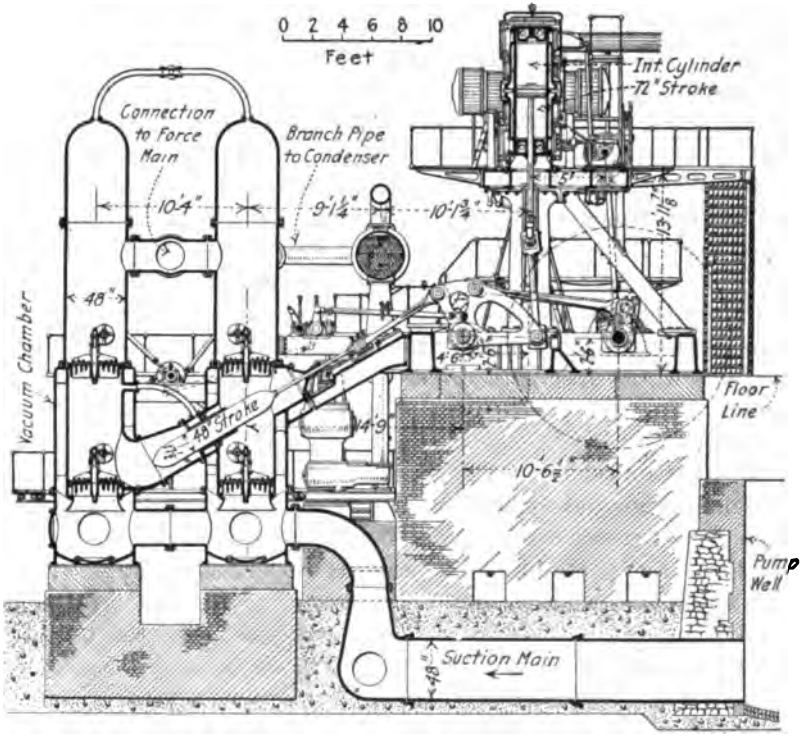

FIG. 11 RIEDLER PUMPING ENGINE, BOSTON WATER WORKS

HOISTING MACHINERY

40 For many years the method of hoisting at both the Calumet and the Hecla mines was by means of constant-running engines, which also drove air compressors. The hoisting drum was on a shaft to which it was not secured except by means of a clutch. There was also a brake to prevent the drum from moving and holding it fast whether the engine was running or not. Both the clutch and brake were operated by means of hydraulic pressure from an accumulator, and the levers for controlling them were interlocked so that the

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clutch and brake could not be thrown on simultaneously. The clutch cylinder was secured to an arm of the flywheel and the water was introduced through the shaft which was bored for the purpose. The brake was secured to a post which was firmly bolted to the foundation. The brakes and clutches were of the strap type and worked on wood. There was an indicator to show the position of the skip in the shaft, and an anti-overwinding device, which I believe was never used. The drum centers were in halves, and were lined continuously with babbitt metal. The rope faces were sometimes straight and sometimes conical, and the arms were of wrought rods.

41 When Mr. S. B. Whiting entered the employ of the Calumet and Hecla Mining Company the Whiting system of hoisting was introduced. This was first used at the Red Jacket shaft, and consisted of two cages, one descending and the other ascending, with a rope from the bottom of one to the bottom of the other, and thus being balanced. The engine drove a pair of narrow-faced drums with two wraps over both drums. The drum shafts were coupled together like the wheels of a locomotive and the engines were reversing.

42 The introduction of reversing engines brought new problems in engine design and the first engines were the Minong and Siscowit. These were vertical triple-expansion condensing beam engines using 185 lb. steam pressure. They had cam-operated gridiron valves with automatic cut-offs on the high-pressure cylinders. The cams were reciprocating. The Walschaerts gear was used, the lap and lead were derived from the beam shaft, and the reversal was effected by hydraulic mechanism. Afterward there were several other installations of the Whiting system with other types of engine. The Minong and Siscowit and Whiting drums are shown in Fig. 12.

43 The first hoisting engines to have conical rope drums, and I believe the only ones, were the Gratiot, Houghton and Seneca. The first two had their drum-shaft axes coincident and the drums on opposite sides of the engines. The engine bedplates were continuous but had their center lines offset sufficiently to enable the crankpins to clear each other and to have them coupled together by a drag link. By this means either drum could be driven by either engine. One drag-link pin was inserted in the main crankpin with a steep tapered fit, and secured by a nut. Generally the drag link was not used, and then the removable pin was taken out.

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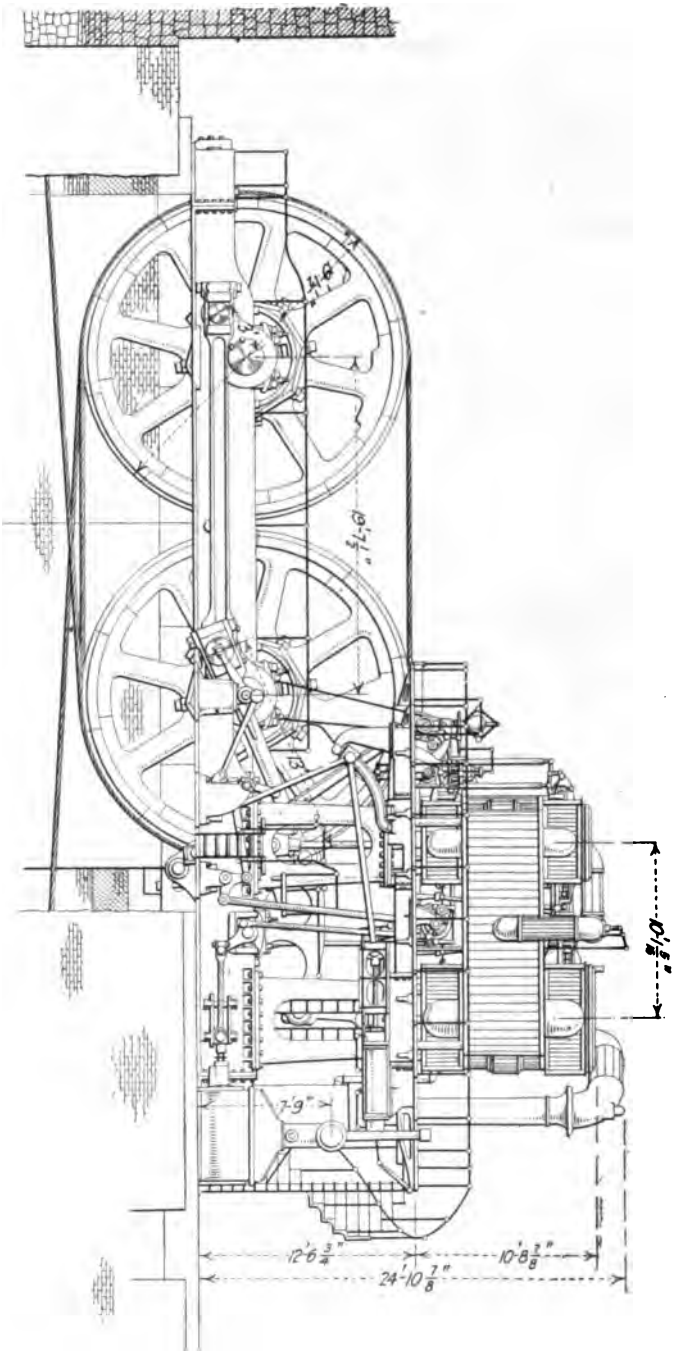

FIG. 12 HOISTING ENGINES *Minong* AND *Siecown*.

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COMMERCIAL ENGINES

44 Mr. Leavitt recommended quite a number of commercial engines for hoisting, pumping and for driving air compressors, but they were usually for spare units or for temporary purposes. For instance, the Superior originally drove hoisting drums on one side and air compressors on the other. On the air-compressor side and beyond the compressors there was a spare Corliss engine which could be coupled on to drive the compressors if the Superior had to be stopped. At the other side there was a 40-in. by 60-in. horizontal condensing Leavitt engine for driving the hoisting drums in an emergency. At the Hecla mine there was an exactly similar arrangement with the Leavitt vertical compound condensing beam engine Fronte-

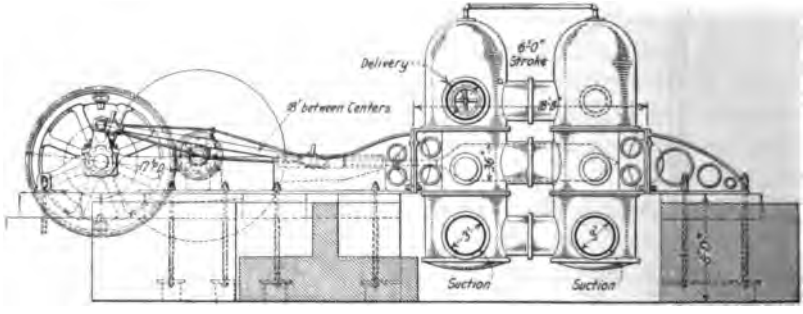

FIG. 13 PUMPING ENGINE *Arcadian*

nac in the middle driving in both directions, with a spare commercial Corliss engine at each end. Similarly there were various commercial engines in other hoisting houses, and not always spare engines. In such cases the commercial part was the smallest.

45 At the stamp mills there were two large-capacity horizontal pumps driven by Brown engines through gears, known as the Huron and Arcadian. The latter is shown in Fig. 13.

46 The pumping engines at the Calumet Water Works, for supplying the town with water were commercial, one being a Worthington high-duty.

47 Condensing and feed water was supplied to the hoisting engines at both the Calumet and the Hecla mines by means of a vertical compound Leavitt beam engine at Calumet Pond which was not far off. This is an interesting engine with the connecting rod on one side of the beam and is shown in Fig. 14.

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AIR COMPRESSORS

48 A great many air compressors are needed at the Calumet and Hecla mines, and up to a certain time commercial compressors were used. Soon after the installation of wet compressors at the St. Gothard Tunnel in Switzerland, Mr. Leavitt was impressed with the advantage of the type and designed a pair of 42-in. by 60-in. 30-r.p.m. wet compressors. These were placed in the Hecla hoisting house and driven by the engine Frontenac. Some years later a

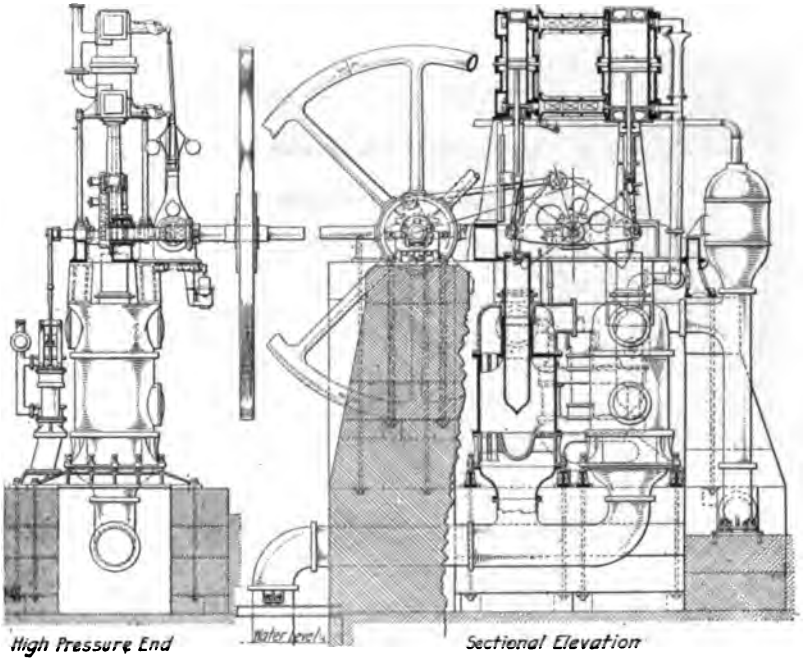

FIG. 14 CALUMET POND. PUMPING ENGINE

duplicate pair was built and placed in the same building. These were similar to double-acting pumping engines, the plunger causing water to rise and fall in two vertical cylinders or chambers one at each end. At the top of each of these chambers there was a valve deck having inlet and discharge air valves, and below there were spray nozzles for cooling the air. The spray water was pumped by a small attached pump. There was a separator in which the vapor settled, and the quality of the air was satisfactory. These compressors were successful, but later when similar ones were installed

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at the Calumet hoisting house to run at double the speed, as I understand, they were unsuccessful on account of that speed and were replaced by dry compressors worked by the same engine, the Mackinac. This was a vertical inverted-beam triple-expansion engine having two 58-in. by 90-in. low-pressure cylinders at one end of the beam, and the high and intermediate cylinders (29 in. and 51¼ in.) at the other end. This engine has the guides, crossheads and links below the beam. See Fig. 16.

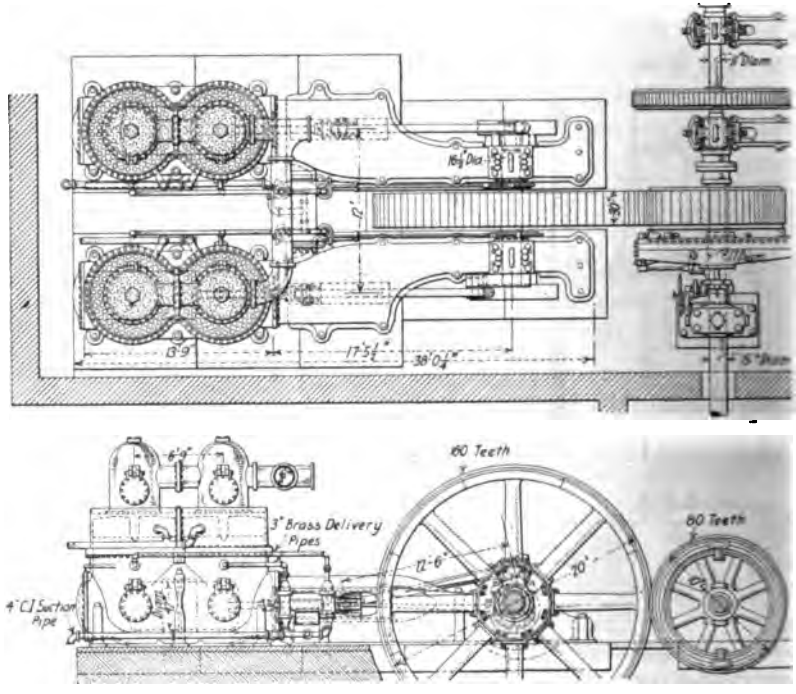

FIG. 15 42-IN. × 60-IN. HECLA WET COMPRESSORS

PUMPING ENGINES

49 Something has already been said about Leavitt pumping engines, and it is well to state that the Lynn type of engine was used only at Lynn and Lawrence. When the first engines were designed for the Calumet and Hecla Mining Company they were inverted, and with the high-pressure cylinder inclined for the purpose of having the cylinders as near together as possible and thus reducing certain losses. Between the near ends of the cylinders

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there was a single valve which was both high-pressure exhaust and low-pressure inlet. At the distant ends there were two valves which moved simultaneously, one being the high-pressure exhaust and the other the low-pressure inlet, although the Lynn engine had only one valve between the distant ends of the cylinders. Later, when the Boston sewage (Fig. 3) and the Calumet Pond (Fig. 14) pumping engines were designed the cylinders were all vertical and reheaters were used. The pumping engine Ontario at the Calumet and Hecla stamp mill which was designed at about the same time had the high-pressure cylinder inclined and had no reheaters. See Fig. 17.

FIG. 15a 42-IN. × 60-IN. WET COMPRESSORS

50 The greatest requirement for water at the Calumet and Hecla mine is at the stamp mill which is some six miles from the mine, on Torch Lake, which is an inlet from Lake Superior. The pumping engine Ontario and the spare pumps Huron and Arcadian already referred to are there. The engine Michigan is the largest engine at the stamp mills, and has cylinders 18 in., 27¾ in. and 48 in. by 90 in. and two plungers with the suction ends 48 in. by 90 in. The number of revolutions per minute was intended to be 30 and the capacity 60,000,000 gal. in 24 hours. It runs usually at 28½ r.p.m. The head is about 40 ft. This engine uses steam of 185 lb. pressure. The Michigan was a bold design, as it is supported by wide, straddling cast-iron columns as shown by Fig. 18. This en-

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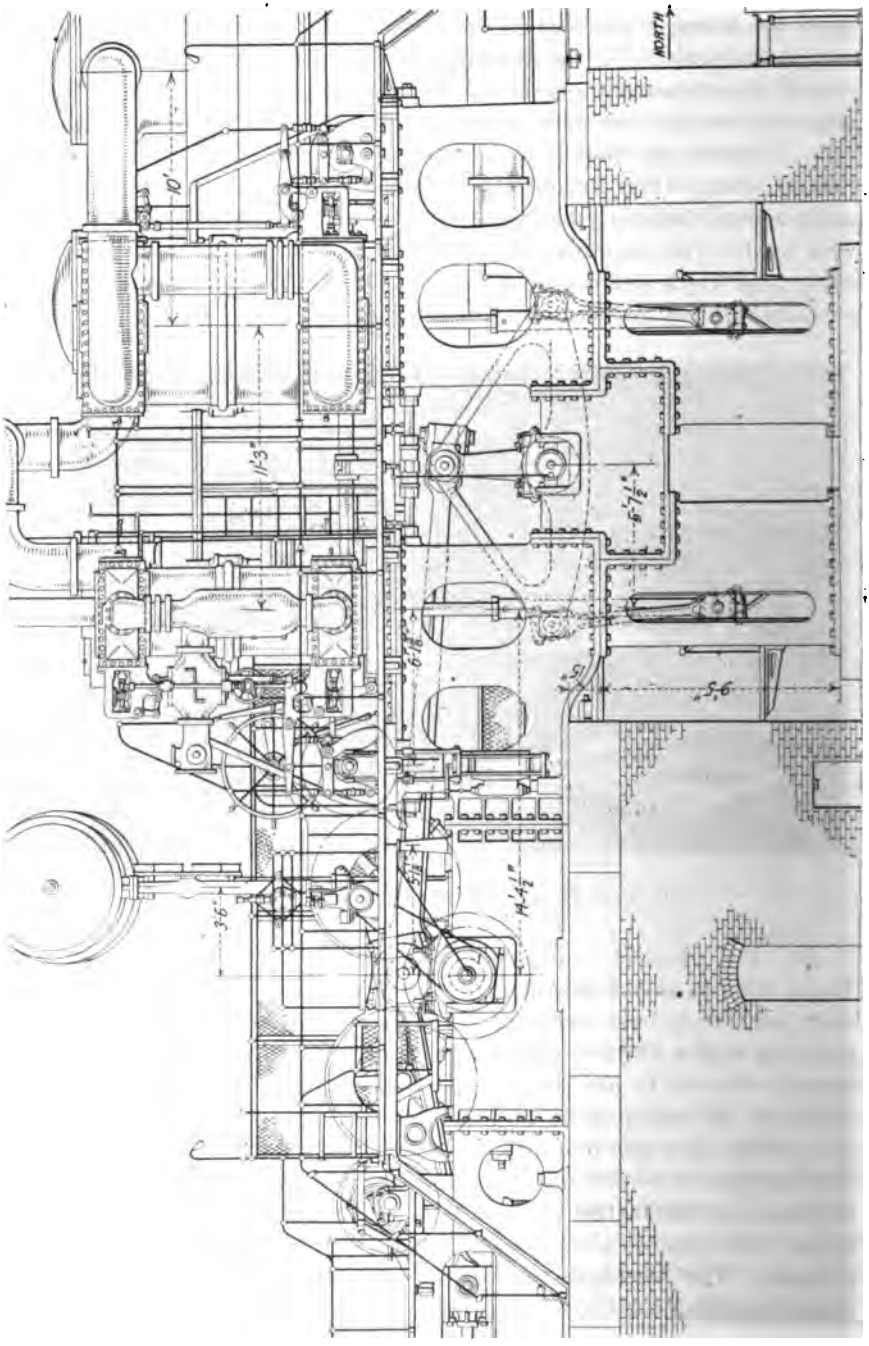

FIG. 16 COMPRESSOR ENGINE *Mackinac*

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gine had pump cylinders which were oval at the valve level for accommodating the valves, and were of great size, being 9 ft. 10 in. wide the narrow way and 13 ft. 2 in. the other way. They were cast of gun iron. (Fig. 19.)

51 The Lynn and Lawrence engines had each one plunger, this being of the Thames-Ditton type, being single-acting on the suction and double- on the discharge, with a few large double-beat metal valves. This type of plunger was not used later, but in-

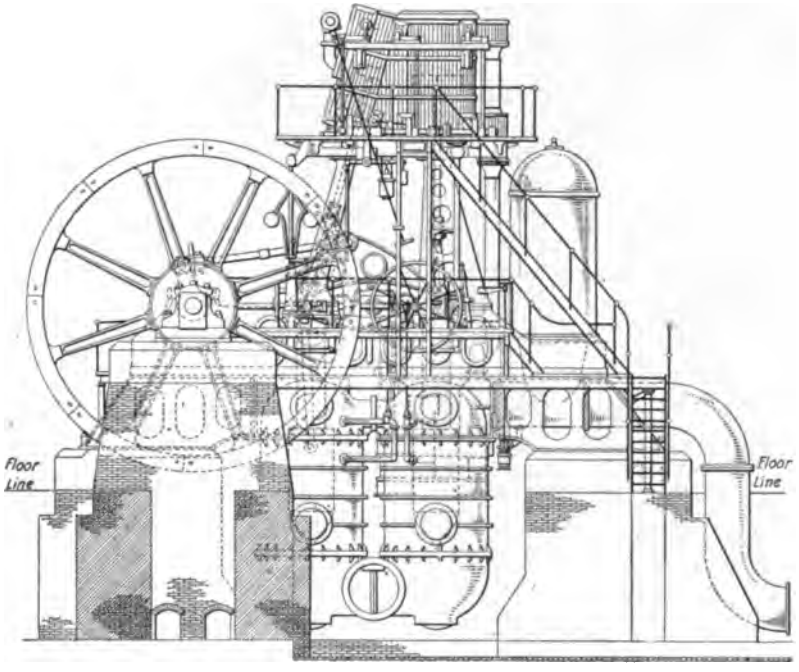

FIG. 17 PUMPING ENGINE *Ontario*

stead of this the differential plunger was used. This plunger is of two diameters, the lower part having twice the cross-section of the upper. The lower section passed through the discharge valve deck and the upper section through the top of the pump. This plunger is single-acting on the suction and double- on the discharge, and two were always used, one being under each end of the beam. The differential plunger was invented by Mr. Leavitt, but he soon found that he was anticipated in this.

52 The sewage engines designed for the City of Boston had each two plungers of a single diameter.

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53 The largest Leavitt pumping engine, designed in 1889 and built by the I. P. Morris Co., was the last sewage engine for Boston, already referred to, the cylinders being 18½ in., 33 in. and 52¾ in.

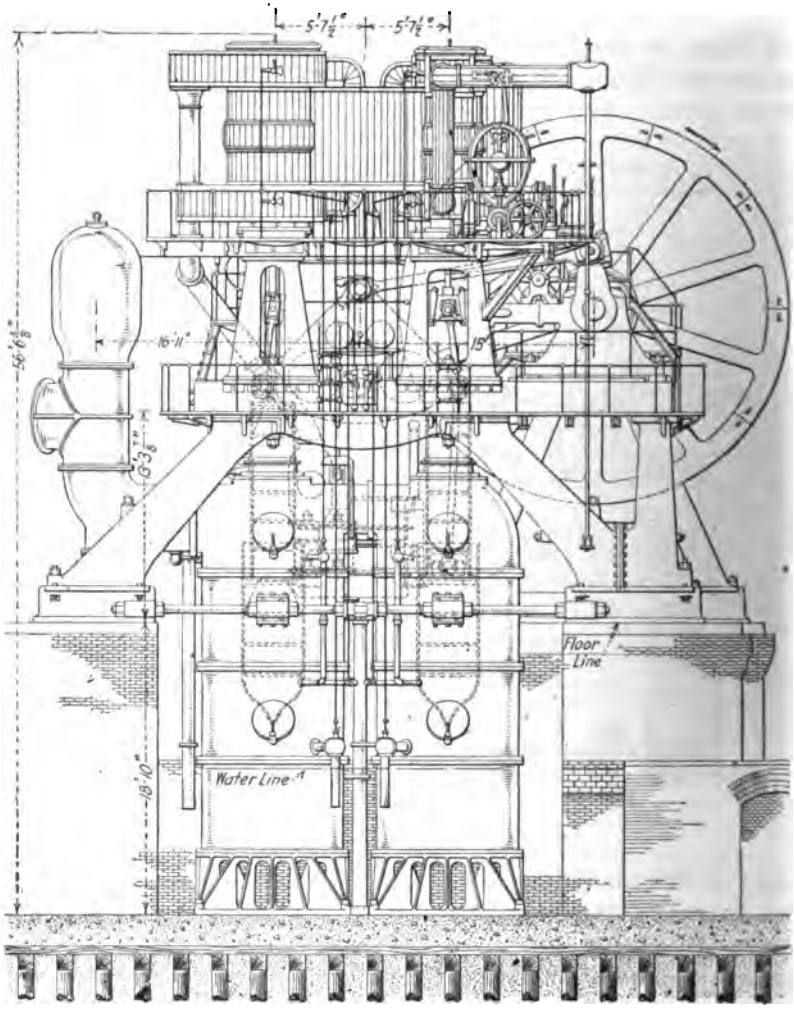

FIG. 18 PUMPING ENGINE *Michigan*

by 10 ft. stroke. The plungers, of which there are two, are 60 in. in diameter by 10 ft. stroke, and the rated capacity 75,000,000 gal. in 24 hours against a head of about 40 ft. The speed is 18 r.p.m.

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54 The sizes of the cylinders and plungers of the Louisville engine have already been given. As this engine was located on the edge of the Ohio River, where the maximum rise and fall of the water was about 60 ft., the engine is high enough to be always above high water, and the pump chambers long enough to reach below low water. The building, foundations, and pumps rest upon a timber caisson. (Fig. 4.)

FIG. 18a UPPER PART OF PUMPING ENGINE *Michigan*

55 The Cambridge engine, designed in 1895, and built by the De La Vergne Machine Co., New York, was a triple-expansion engine, using 185 lb. pressure. The cylinders were 18½ in., 33 in., and 52¾ in. by 7 ft. 6 in. stroke, and the plungers (two differential) 19⅜ in. and 27¾ in. by 7 ft. 6 in. stroke. Its rated speed was 32 r.p.m. and this gave a piston and plunger speed of 480 ft. per min. and a capacity of 20,000,000 gal. in 24 hours. If the engine had run slower it would have been more satisfactory.

56 At about the time the Cambridge engine was designed Mr. Leavitt was commissioned with the design of a pair of engines

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for the city of New Bedford, Mass., which were built by the Dickson Mfg. Co. It was decided to make these engines compound and to use 185 lb. pressure, in order to compare their economy with that of the Cambridge engine using the same steam pressure

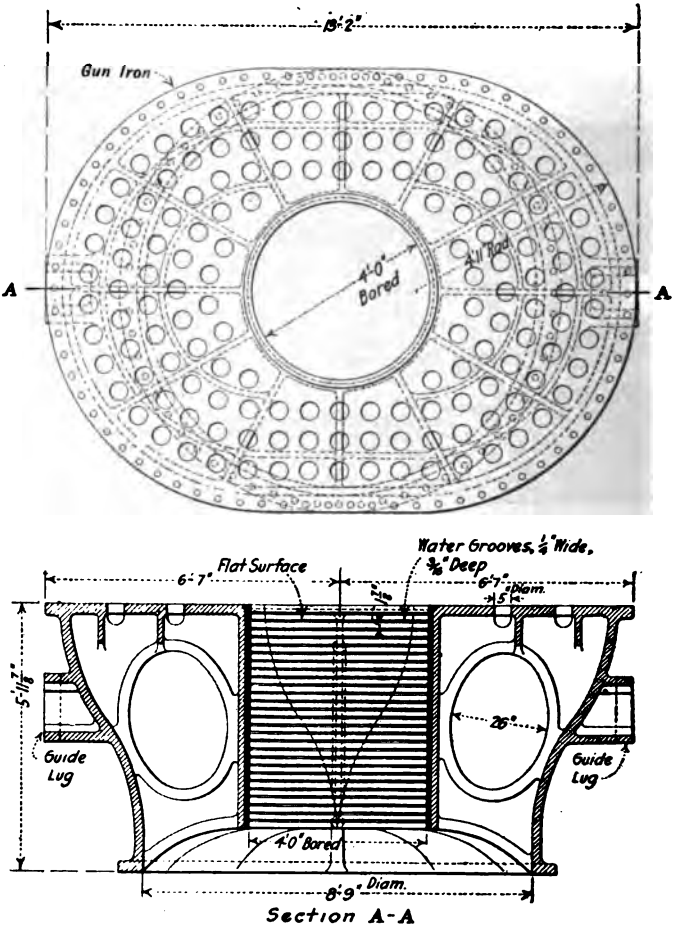

FIG. 19 DISCHARGE-VALVE SEATING, ENGINE *Michigan*

and being triple. I do not know whether the comparison was ever made, but the station economy of the New Bedford engines is better than that at Cambridge. The steam cylinders of the New Bedford engines are $16\frac{3}{8}$ in. and $36\frac{1}{4}$ in. by 7 ft. 6 in. stroke, and the pump plungers are $13\frac{7}{10}$ in. and $19\frac{3}{8}$ in. by 7 ft. 6 in. stroke. (Fig. 20.)

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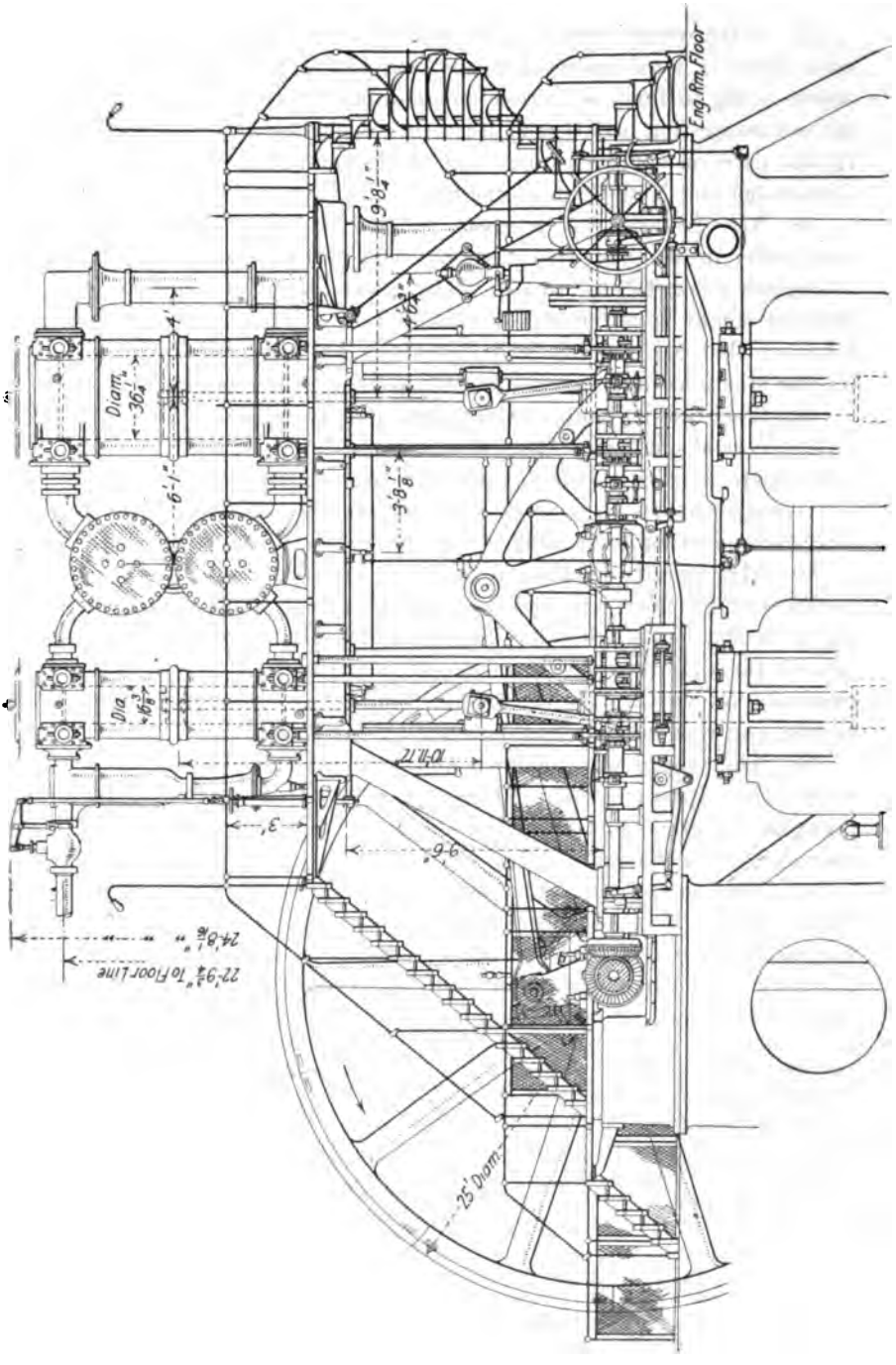

FIG. 20 NEW BEDFORD PUMPING ENGINE

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57 A feature of some Leavitt pumps is that under each suction valve there is a tube several inches long with a bell lower end, the object being to form a suction air chamber between the tubes. I am not aware that any benefit from this construction was identified. It was used on some Calumet and Hecla engines, and also on the Cambridge and New Bedford engines.

58 Mr. Leavitt was a great believer in steam jackets, and used boiler pressure for this purpose, even in low-pressure cylinders of engines using 185-lb. steam. It is known that these engines exhausted steam considerably superheated into the condensers, but I believe that Mr. Leavitt held that there was great benefit in drying the steam as much as possible before it left the cylinder.

59 The Leavitt pump valves were not as small as those used in commercial engines. They were usually faced with leather and had separate adjustments for the lift and tension of the spring. For sewage engines the valves were rectangular and hinged on one side, each covering an opening of 4 in. by $16\frac{3}{4}$ in. in the latest engine.

60 Mr. Leavitt became acquainted with Professor Riedler of Berlin, and I believe acquired the right for a time to use the Riedler pump in the United States. The Riedler pumping engine for the city of Boston, already referred to (Figs. 10 and 11) was a triple-expansion 3-cylinder, 3-beam, 3-connecting rod, 3-crank and 3-pump engine, and was the only one designed by Mr. Leavitt.

61 The pumps were inclined and double-acting, located at the rear of the engine and operated by connections to the beams. Each pump had a single suction and a single discharge valve at each end operated by mechanism.

62 The engine was built by the Quintard Iron Works, New York. As it was intended to surpass all previous efforts at economy, the results of a test made by some students of the Massachusetts Institute of Technology under the direction of Prof. Edward F. Miller are herewith given:

Diameter of high-pressure cylinder, in.	13.7
Diameter of intermediate-pressure cylinder, in.	24.375
Diameter of low-pressure cylinder, in.	39
Stroke of each piston, in.	72
Diameter of each plunger, in.	17.5
Stroke of each plunger, in.	48
Rated capacity in 24 hours at 50 r.p.m., gal.	20,000,000
Type of condenser	surface
Steam pressure, lb. per sq. in.	185
Type of boiler	Belpaire locomotive

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Duration of trial, hours	24
Average number of revolutions per minute	50.585
Average steam pressure at throttle, lb	175.7
Average vacuum in condenser, in	27.25
Average pressure in first receiver, lb	46.5
Average pressure in second receiver, lb	2.4
Average pressure in high and intermediate cylinder jackets, lb	175.7

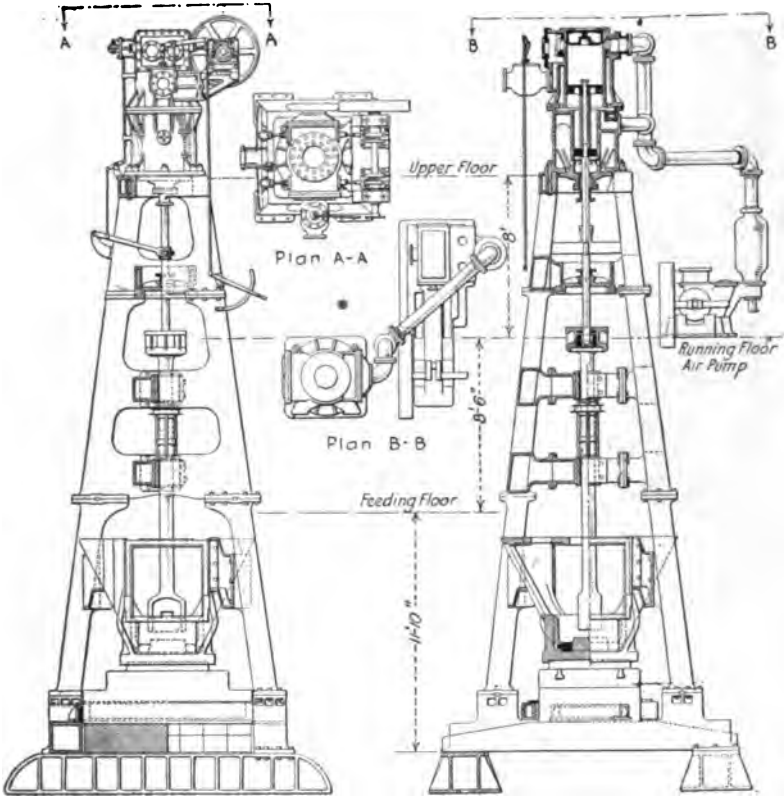

FIG. 21 LEAVITT ROCK STAMP

Average pressure in low-pressure cylinder jacket, lb	99.6
Indicated horsepower of high-pressure cylinder	150.86
Indicated horsepower of intermediate cylinder	186.14
Indicated horsepower of low-pressure cylinder	238.66
Total steam horsepower	575.66
Total pump horsepower	529.86
Mechanical efficiency, per cent	92
Friction, per cent	8

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Water discharged in 24 hours by weir measurement, gal.	21,016,000
Slip, per cent	1.83
Dry steam used per i.hp-hr., engine only, lb.	11.22
Coal used per i.hp-hr., whole plant, lb.	1.18
Duty per 100 lb. coal, ft-lb.	150,045,000
Duty per 1,000,000 B.t.u., ft-lb.	145,470,000
Duty per 100 lb. combustible, ft-lb.	160,000,000

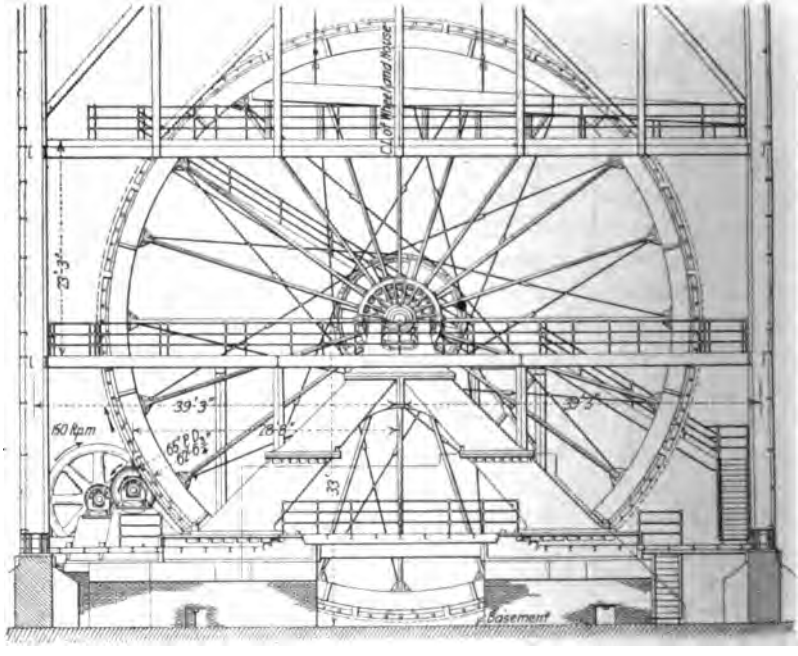

FIG. 22 65-FT. SAND WHEEL

THE LEAVITT STAMP

63 The steam stamp devised by Mr. Leavitt for stamping rock containing native copper is a gigantic steam hammer about thirty-eight feet high above the foundation. (Fig. 21.) When Mr. Leavitt began to study economy of steam for stamps he found great room for improvement, and then devised his well-known stamp. It has two pistons on the same rod, the upper one being considerably larger than the lower. Steam for the blow acts upon the top of the upper or larger piston and is admitted by a gridiron valve, and exhausted by another to a condenser. Both valves are operated by cams. The space between the upper and lower pistons is con-

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stantly connected to the condenser. The space under the lower piston is occupied by live steam and serves to lift the stamp, and the steam thus used is churned into and out of a reservoir, and thence to and from the steam pipe. The lower piston enters a compression chamber at the bottom to limit the downward stroke, while the upward stroke is limited by a still lower piston entering a dashpot.

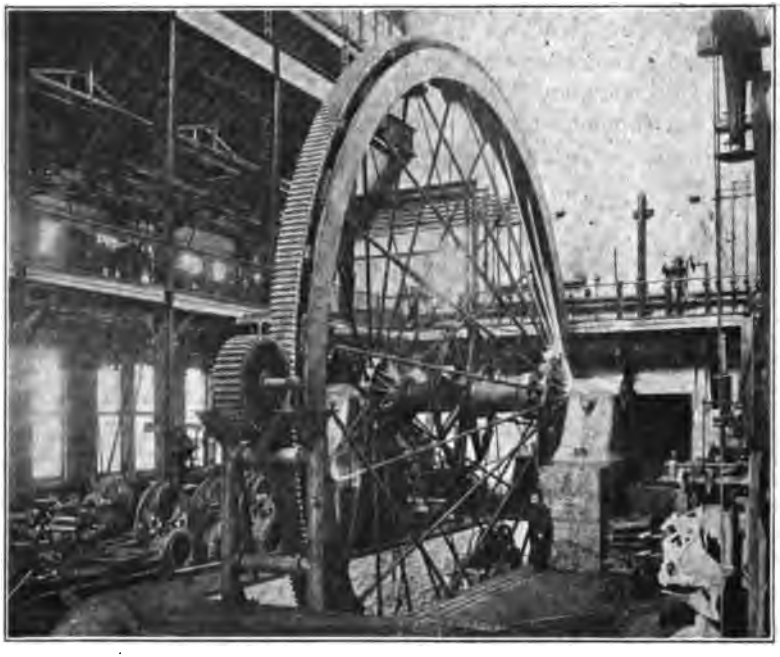

FIG. 23 "50-FT." SAND WHEEL WITHOUT BUCKETS. CUT GEARS

Diameter of pitch circle, 54 ft.
Width of face, 18 in.
Pitch of teeth, 4.71 in.

64 As appears to have been the custom at the Lake Superior mines, the stamp anvil, which has been made of various weights, rested formerly on large maple spring timbers. In about 1900 these were omitted and the anvil placed directly on the foundation. By this means the output of the stamp was increased and the vibration of the surrounding territory diminished. There are 27 Leavitt stamps at the Calumet and Hecla stamp mills, each making 108 blows per minute.

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65 The valve gear and condenser pump are driven from a shaft which serves a long line of stamps. Later, I understand, the exhausts of all of the stamps were taken to low-pressure turbines, with the result that some of the power engines were shut down, and considerable economy resulted.

66 It is unfortunate that Mr. Leavitt could not have been active long enough to realize the merits of the steam turbine. As far as I talked with him he could see no merit in turbines, but if he could have known of the application of the low-pressure turbine to the stamp exhausts he would undoubtedly have been impressed.

67 I do not know whether he was aware of the influence of the recent development of the centrifugal pump, turbine- or motor-driven, upon the future of reciprocating pumping engines.

SAND WHEELS

68 The prevailing method of disposing of the sand and water from the Calumet and Hecla stamp mills is to conduct them to buckets rigidly secured to each side of the rim of a large wheel called a sand wheel. These buckets are open toward the center of the wheel and receive the sand and water when at their lowest position from a trough called a "launder." When they arrive toward the top they begin to empty into a pan from which the sand and water flow to the dump.

69 In Mr. Leavitt's design the sand wheel had a gun-iron shaft, a cast-iron rim and arms of steel rods disposed like bicycle spokes. A spur gear was bolted to the rim of the wheel and driven by a pinion. Fig. 22 shows a sand wheel having a cut gear of 65 ft. pitch diameter. Fig. 23 shows a photographic reproduction of a 50-ft. wheel.

BOILER PRACTICE

70 Mr. Leavitt was a great advocate of the locomotive boiler and usually installed this type. I understand that before adopting it he designed some boilers for the Calumet and Hecla mine which were a sort of "elephant" boiler, and these were failures. After this the locomotive type was always used, and these were a great success. They had a firebox with a mid-water leg, thus forming two fireboxes. The mid-water leg extended forward from the firebox and formed two so-called flues to a single combustion chamber which ended at the tube plate. The length of the flues was often 3 ft. 6 in. and the combustion chamber 4 ft. At the end of the

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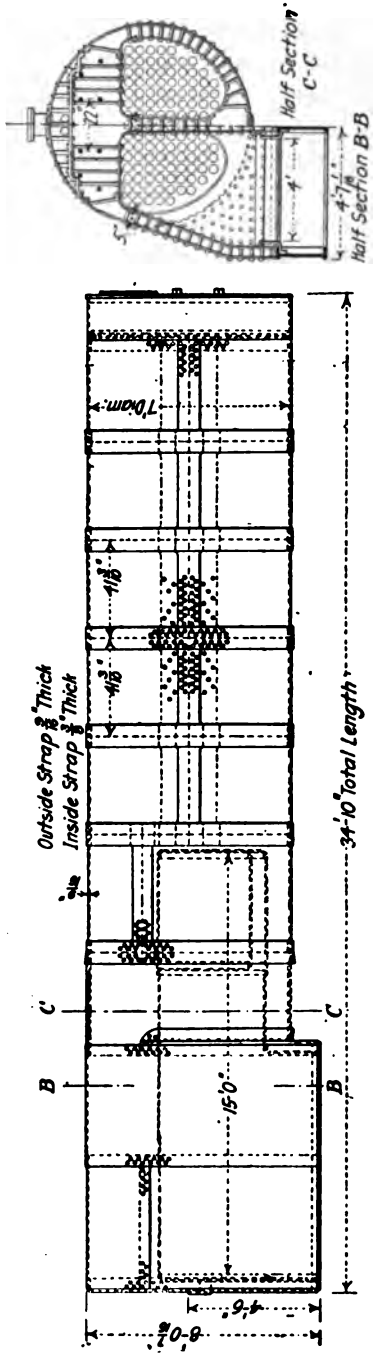

FIG. 24 LOCOMOTIVE TYPE BOILER OF 1879

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grate there was a 20-in. firebrick wall, thus making the distance from the end of the grate to the tubeplate 9 ft. 2 in. In 1882 or thereabout brick arches began to be used, as in locomotive practice.

71 Originally the boilers had a round top above the crown sheet, but later, due to the writer's influence, the Belpaire form of firebox and method of staying was adopted. Up to about this time the joints in the barrel of the boiler were butted, both longitudinal and circumferential, but Mr. Leavitt was influenced to abandon the latter for lap joints. The longitudinal butt joint was, of course, preserved, and it is interesting to know that the prevailing form of butt joint used in this country, viz., that having a narrow outside and wide inside strap, was devised by Mr. Leavitt and Edward Kendall of Cambridge, Mass., where Mr. Leavitt also lived. This joint was then thought to be the final word in joint efficiency, and the drawing of the first boiler having it was made in 1879 and is here reproduced. The drawing also shows the butted circumferential seams. (Fig. 24.)

72 Why Mr. Leavitt did not adopt English practice in butt joints, with which he must have been acquainted, I do not know, but I suppose that he was seeking a joint of higher efficiency than that, as then designed, which had the straps of equal widths and all rivets in double shear.

73 The Belpaire form of the Leavitt boiler is shown in Fig. 25. This boiler is the design for 185 lb. pressure. It was very expensive, and the largest size had only 2900 sq. ft. of heating surface and 68.75 sq. ft. of grate. In 1887 the cost per square foot of heating surface was about $5.20 for 90-in. boilers for 185 lb.

74 For mill work Mr. Leavitt used the horizontal return-tubular boiler, and some of them 78 in. in diameter carried 185 lb. pressure. For the New Bedford pumping engines he used cylindrical boilers with two Purves furnaces each and 3-in. tubes from the furnaces to a smokebox.

STEEL FORGINGS AND WORKMANSHIP

75 Mr. Leavitt was always an admirer of Krupp forgings. In the early eighties he had some forgings made in Pittsburgh, among which was a 15-in. shaft 30 ft. long, which had a 3-in. hole bored from end to end at Scranton, Pa. At 6 ft. from one end there was a transverse crack extending almost to the circumference, and this was the signal for the abandonment of American forgings. After

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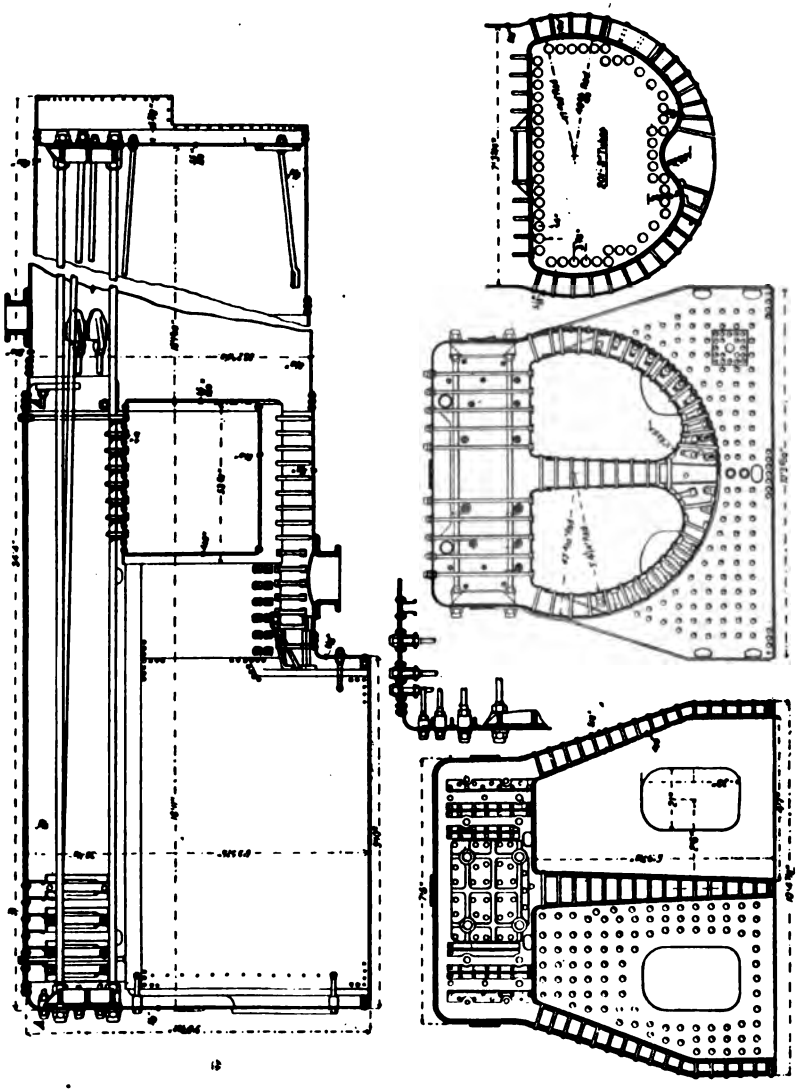

FIG. 25 BELPAIRE FORM OF THE LEAVITT BOILER

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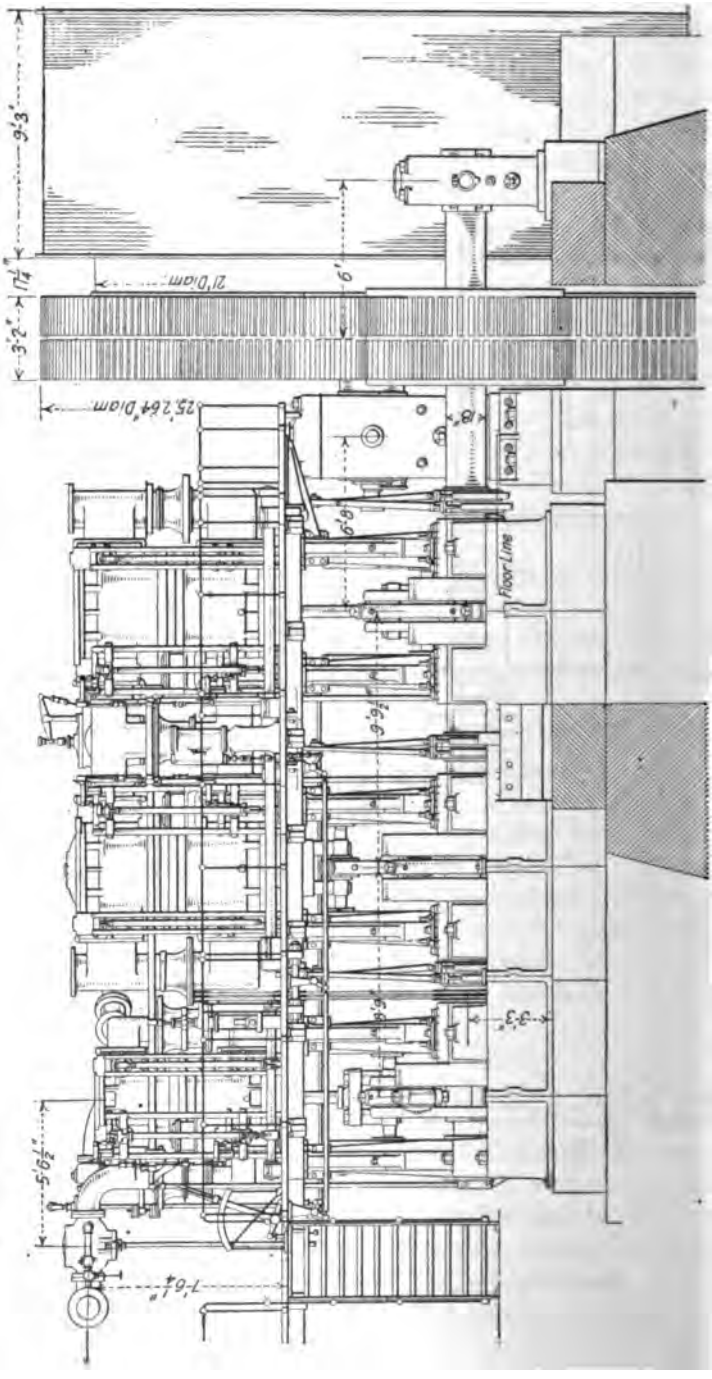

FIG. 26 THREE-CRANK HOISTING AND POWER ENGINES

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this they all came from Krupp's, and they were usually finished and polished by Krupp. Mr. Leavitt for some time kept an American inspector at Krupp's works. It is interesting to note that a large crankpin which came from Pittsburgh with the 15-in. shaft, while in service, suddenly parted in the middle of the connecting-rod box and the outer piece fell out. It was found to have the same kind of defect as the shaft.

76 Mr. Leavitt would not tolerate poor workmanship, and requirements were more and more exacting as time went on. In early practice cranks were shrunk on shafts, but later they were forced on with tapered fits, using $\frac{1}{16}$ in. per foot over all, thus adopting locomotive-driving-wheel practice. Similarly bolts in some places were thus fitted. Valves and valve seats were scraped to fit, and in later practice they were tested where built under steam of the working pressure.

CONSULTING ENGINEERING

77 So far as I know, Mr. Leavitt did not do much general expert work, but he acted as consulting engineer for a number of companies. Among them were Henry R. Worthington and the Dickson Mfg. Co. He designed the Penn Avenue shop for the latter company at Scranton, Pa. This was a well-lighted shop with a high center bay and traveling crane, and a gallery on each side.

78 Mr. Leavitt's influence upon good designing in this country must have been great, and the many draftsmen whom he employed and who have scattered throughout the country must have exerted a great and silent influence upon excellence in design, which they owe to him. I feel that William Sellers, E. D. Leavitt, John E. Sweet and Charles T. Porter were the best machine designers that this country has produced up to their time. Mr. Leavitt willingly gave credit to the other three for much of his own good work.

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TABLE 1 PUMPING ENGINES DESIGNED OR SPECIFIED BY MR. E. D. LEAVITT FOR THE CALUMET AND HECLA MINING CO

Name	Type	Capacity in million gal. 24 hr.	Steam-cylinder dimensions, in.	Plungers						
				Type	No.	Diam., in.	Stroke, in.	Location	Erected	Note
No. 1 Erie.....	Vertical rocker compound	10	11½ & 24 × 54	bucket	2	16½ & 23	54	Lake Linden	1874	Dismantled 1904
No. 2 Ontario....	Vertical rocker compound	20	17½ & 36 × 60½	differential	2	20 & 33	60½	Lake Linden	1876	
No. 3 Huron.....	Horisontal, simple	20	18 × 48	double-acting	1	36	72	Lake Linden	1882	Brown eng., Leavitt pump
Michigan.....	Vertical rocker, triple expansion	60	18 & 27½ & 48 × 90	differential	2	34 & 48	90	Lake Linden	1888	
Arcadian.....	Horisontal tandem compound	20	13 & 26 × 42	double-acting	1	36	72	Lake Linden	1901	Brown eng., Leavitt pump
Minnehaha.....	Vertical rocker compound	5	11½ & 24 × 48	single-acting	2	17	48	Cal. Pond W. W.	1881	
Nipigon.....	Horisontal compound	10	21 & 42 × 36	double-acting	4	27½	36	Cal. Pond W. W	1888	Worthington high-duty pump
Portage.....	Horisontal compound	3	14 & 24 × 36	double-acting	4	18	36	Cal. Pond W. W.	1880	Worthington pump
Heriot.....	Vertical triple-expansion 3-crank	15	18 & 33 & 54 × 36	double-acting	6	19	36	Cal. Pond W. W.	1900	Snow pump
Nipissing.....	Horisontal compound	1	19½ & 33½ × 24	double-acting	4	9	24	Lake Sup. W. W.	1889	Worthington pump
Pepin.....	Horisontal double tandem, triple-expansion	2	17 & 29½ & 34 × 36	double-acting	4	7½	36	Lake Sup. W. W.	1896	Snow pump

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TABLE 2 ENGINES DESIGNED OR SPECIFIED BY MR. E. D. LEAVITT FOR THE CALUMET AND HECLA MINING CO.

Name	Type	Cylinders						Stroke, in.	Service	Erected	Note
		H.P.		Int.		L.P.					
		No.	Dia., in.	No.	Dia., in.	No.	Dia., in.				
Perrot	Horisontal, simple	1	30	....	....	....	....	48	Compressing	1883	
Hancock	Vertical rocker, triple-expansion, 3-crank	1	20½	1	31½	1	50	48	Hoisting	1892	
Pewabic	Vertical rocker triple-expansion, 3-crank	1	20½	1	31½	1	50	48	Hoisting	1892	
Detroit & Onota	Horisontal tandem compound	2	18	....	....	2	32	48	Hoisting	1889	
Woodruff & Beach	Horisontal, simple	2	20-$\frac{3}{16}$	....	....	....	....	48	Hoisting	1869	
2 Lake Erie engines	Vertical triple-expansion, 3-crank	1	9	1	14½	1	22½	18	Each driving	1896	Not in use
2 Lake Erie engines	Vertical triple-expansion, 3-crank	1	7½	1	12	1	19	16	Each driving	1895	Not in use
Saginaw	Vertical tandem compound	2	17	....	....	2	40	48	Each driving	1902	
Osage	Vertical rocker compound, 3-crank	2	24	..e.	....	2	40	48	Originally hoisting, now generating electricity		
Owego	Vertical rocker compound, 3-crank	1	24	....	....	2	40	48	Originally hoisting, now generating electricity		
Ontonagon	Vertical rocker compound, 3-crank	1	24	....	....	2	40	48	Originally hoisting, now generating electricity		
Winnebago	Vertical compound	1	23	....	....	1	40	20	Generating electricity	1893	Westinghouse engine. Not in use
Ottowa	Vertical compound	1	23	....	....	1	40	20	Generating electricity	1893	Westinghouse engine. Not in use
No. 7 man hoist	Vertical compound, 3-crank	1	14	....	....	2	24	30	Hoisting	1902	De La Vergne engine
No. 8 man hoist	Vertical compound, 3-crank	1	14	....	....	2	24	30	Hoisting	1902	De La Vergne engine

Note. — Most of the Leavitt machinery for the Calumet and Hecla Mining Co. was built by I. P. Morris & Co. and (later) I. P. Morris Co.

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TABLE 3 ENGINES DESIGNED OR SPECIFIED BY MR. E. D. LEAVITT FOR THE CALUMET AND HECLA MINING CO.

Name	Type	Cylinders						Stroke, in.	Service	Erected	Note
		H.P.		Int.		L.P.					
		No.	Dia., in.	No.	Dia., in.	No.	Dia., in.				
Wabeek (original)	Vertical rocker compound	1	22½	....	....	1	38	60½	Driving	1876	In Frontenac house. Moved to Lake Linden 1888, broke down 1894
Wabeek (new)	Vertical rocker triple-expansion	1	18	1	27½	1	48	60	Driving	1895	
Superior	Vertical rocker compound	1	40	....	...	1	70	72	Originally hoisting and compressing, now compressing	1881	
Baraga	Horizontal, simple	1	40	....	....	....	....	60	Originally hoisting, now compressing	1883	
Frontenac	Vertical rocker compound	1	27½	....	....	1	48	72	Compressing	1883	
Gratiot	Vertical rocker, triple-expansion	1	18	1	27½	1	48	90	Originally hoisting, now generating electricity	1888	Moved to Lake Linden 1902
Houghton		1	18	1	27½	1	48	90	Hoisting	1888	
Seneca		1	18	1	27½	1	48	90	Hoisting	1888	
Minong & Siscowit		2	20½	2	31½	2	50	72	Hoisting	1891	
Mesnard & Pontiac		2	20½	2	31½	2	50	72	Hoisting	1891	
Delaware & Iroquois	Horizontal tandem compound	2	16	....	....	2	32	48	Hoisting	1891	Corliss engine
Marquette & Chippewa		2	17	....	....	2	34	60	Hoisting	1896	Corliss engine
Minnesota & Escanaba		2	18	....	....	2	36	60	Hoisting	1899	Rice and Sargent engine
Illinois & Wisconsin		2	18	....	....	2	36	60	Hoisting		Rice and Sargent engine
Mackinac	Vertical rocker triple-expansion	1	29	1	51½	2	58	90	Compressing	1896	
Rockland	Horizontal, simple	1	30	....	....	....	....	48	Compressing	1880	Corliss engine
La Salle	Horizontal, simple	1	30	....	....	....	....	72	Compressing	1883	Corliss engine

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No. 1624

LABOR-TURNOVER RECORDS AND THE LABOR PROBLEM

By Richard B. Gregg,[1] New York, N. Y.
Non-Member

The application of rational methods of analysis to the conduct of the operative details of industrial establishments has long been accepted as an effective means of approaching the maximum efficiency of output, and in recent years production problems of all kinds have been studied and solved by such methods. In this paper the author advocates the application of a similar mode of analysis to an increasingly important phase of the labor problem, namely, the labor turnover, or the shifting of workers from one place of employment to another. He considers various causes that have given rise to the problem and suggests other aspects of the subject that still remain to be explored, leaving a discussion of the remedies which have proved successful for future treatment.

AS a way of obtaining truth the scientific method is capable of expansion to many regions of human activity hitherto explored only very superficially. One problem which has recently been illuminated by the application of this method is that large group of difficulties known as the labor problem, — perhaps the most perplexing, complex, insistent, and far-reaching problem we are now facing. It has affected and will continue to affect more people even than this war and will outlast it by many generations. This paper discusses one aspect of the problem which, although only a small corner of the whole question, is even by itself of great importance.

2 The particular part of the labor problem which scientific method has recently done much to clarify is that shifting of workers from one place of employment to another, known as labor turnover. Some refer to it as "hiring and firing." The subject has been written and talked about considerably in the last two or three years,

[1] 814 Flatiron Bldg.

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers.

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and no doubt is very familiar to most people. The time has come now when we can profitably examine its scientific aspect in order better to realize its implications and extend its usefulness.

3 The study of labor turnover is the measurement of the movement of industrial workers in and out of their employment, and the analysis of its causes and results. The value of such study is patent to everyone who has ever handled employment. The difficulty of training a continually shifting force, the low quality and quantity of production obtainable from tramp workers, the lack of team-play, low standards, poor tone, discontent and unrest in an establishment where the labor turnover is high, — all these are factors that gravely affect both the annual balance sheet and the ease and effectiveness of management.

4 There is, of course, a certain amount of labor turnover which is unavoidable and normal. A factory will always be losing employees from old age, death not caused by industrial accident or occupational disease, marriage, changes of residence or domestic events wholly uninfluenced by the character of work or pay. What this normal amount will be, will vary from factory to factory according to local conditions. A careful estimate in one instance placed it at 21 per cent of the total working force. The amount of turnover in excess of this normal, excepting lay-offs due to slackening demand for product, may be considered a kind of barometer of dissatisfaction, either of employer with employee or of employee with position. The quittings are in effect a sort of gradual continuous strike. These things demand careful thought.

5 Let us imagine a factory where there is a high labor turnover with all its consequent difficulties. What would it mean to apply scientific methods to this problem, and what would be the probable results?

6 First of all we must get the facts. How great is the labor turnover? To get this we must examine the payroll or keep a record of the hirings and quittings and discharges from the entire factory for a given period of time — say a year. By comparing the total number of leavers for all reasons with the total normal number of workers in the factory we may obtain the turnover in terms of percentage, which is useful for comparisons with other periods or other groups of workers. In getting the percentage for a smaller group, the basis will be the normal number in that group. For purposes of thorough analysis it will be well to obtain the amount and percentage of turnover for each department and each job within

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the departments. In one factory the annual turnover for the entire concern for several successive years was in the region of 45 per cent. Again, in one department in a certain cotton mill the turnover last year was over 500 per cent. The turnover on some positions will occasionally run much higher than that. These figures, after making allowances for lay-offs and normal turnover, point to economic defects and begin to clarify our problem.

7 Having obtained the annual turnover *in toto* and in detail in this fashion, we will get further light on the situation by working out the turnover for each week and for other divisions of the year such as each of the thirteen four-week periods. In this way we learn whether there are any seasonal or periodic fluctuations. In some industries, such as the building trades or the manufacture of clothing, such variations are very marked.

8 It is obvious that these measurements and analyses tend to make it more possible to learn the causes for the turnover. Once we learn real causes and definitely locate responsibilities, we are in a position to begin to control the phenomenon.

9 Carrying out our analysis and arrangement of facts still further, we can often obtain very valuable indices of the reasons for high labor turnover. For instance, grouping the leavers according to their actual earnings will show the significance of the wage factor as a cause for leaving. To illustrate how this works out: A certain cotton mill learned that there was a high labor turnover in its power department. Upon further analysis the turnover was found to be confined almost entirely to the coal handlers. Inquiry showed that these men were receiving fifty cents a week less than the coal handlers at the local railroad station. The wage was raised fifty cents, the turnover ceased, and the management was relieved of its worry about demurrage charges. Usually a large part of the shifting will be found in the low-paid groups. The result of most experiments with this fact seem to show that low wages are much more the cause of the high turnover than any inherent and unchangeable characteristics of that group of workers.

10 Other groupings which might prove significant are sex, nationality, age, foremen, rooms, heaviness of work, amount of illumination or ventilation of work place, dirtiness of job, method of pay, amount of accident risk, anxiety, amount of other fatigue factors, distance of workers' homes from the factory, etc.

11 A further aid in learning the causes for leaving is making inquiries from the foremen and from the leavers before they go.

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Not too much reliance can be placed on this information, however, as it is very apt to be distorted or wholly falsified by anger, fear, prejudice and all sorts of personal motives.

12 As a result of all this recording of facts, measuring, weighing, testing, analysis and classification, we find ourselves able to determine the real causes for the turnover in a large number of cases. Sometimes the causes will be simple, as in the case of a motor company which learned that most of its leavers resided a considerable distance away from the plant. By giving preference to applicants living nearby the turnover was gradually reduced very greatly. Usually, however, there is a complex set of causes. Often the apparent cause merely serves to release discontent that has gradually been accumulating for a number of reasons. With patience and skill we can usually arrive near the truth.

13 By further measurement and analysis we can determine, or at least approximate, the cost of losing a worker in a particular position and training another. These costs may be roughly divided into overhead costs and operating costs.

14 Among the overhead costs there are:

1 More rapid depreciation of machinery because of ignorance or lack of skill of new workers

2 Extra floor space and extra machines to provide against idleness of a certain amount of machinery due to shifting labor.

15 Operating costs may include any or all of the following:

1 Time of increased superintendence or office work, including:

a Time spent by foremen or superintendent in discharging a worker where that is the way the vacancy occurred

b Time spent by foreman or other workers in training the new employee

c Time spent by clerks on additional payroll or other records.

2 Machine costs, covering:

a Time machinery is idle when a new worker cannot be obtained immediately

b Idle machinery for temporary stoppages due to ignorance or lack of skill of new worker

c Repairs to machines or renewals of tools broken for the same reason.

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3 Material costs, including:
- *a* Waste or damaged material due to ignorance or lack of skill of new worker
- *b* Difficulties in subsequent processes due to poor work by new employees in previous processes
- *c* Lower production while new employee is working up to his best skill.

4 Additional accident cost due to higher rate of accidents among new employees.

16 These two kinds of overhead costs and four groups of operating costs, while not exhaustive, serve to illustrate the method of observation, recording, measurement and analysis which is just as helpful in this aspect of the matter as elsewhere. With knowledge so obtained the factory manager is in a position to estimate more truly the importance of this problem and to judge whether he can afford to take certain steps to reduce the turnover.

17 As is probably well known, those who have made the most careful studies of this question find that it costs about $10 to replace an ordinary laborer, and as much as $300, and perhaps more, to replace skilled workers. The cost varies of course with the nature of the position. The total losses are, of course, enormous. Mr Magnus Alexander, Mem.Am.Soc.M.E., in his well-known study, estimated the losses in a group of twelve metal-working factories in a single year at not less than $831,000. The annual loss from high labor turnover in a particular textile mill employing about two thousand workers is estimated as at least $20,000. These instances could be multiplied.

18 It should be remembered, moreover, that none of these estimates include the losses to the employees or the community. What frequent job shifting means to the employee and his family in terms of frequent house moving, ill-feeling, discouragement, bitterness, decrease of skill, lowering of pride and self-respect, we have no means of measuring. What it means to the community and nation in terms of underemployment and unemployment, increased pauperism and drinking, inefficiency, and social friction, we cannot even estimate.

19 Everywhere we go we can find the reasons for the labor turnover indicated clearly enough to point out sound remedies, and losses large enough to prove that it is sound business to adopt the remedies and avoid the losses. A description of remedies that have proved successful, interesting as they are, cannot be attempted here.

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20 There are many other aspects of the matter that still remain to be explored. What are the relations between absences and tardiness and labor turnover? Cannot absences and tardiness be studied in the same way as labor turnover? What are to be the relations of labor-turnover control to such problems as trade education, promotion policies, the intellectual life of the industrial community, the mobility of labor, scientific management, women in industry? Will it be wiser to leave the broad problem of control of labor turnover entirely in the hands of employers, or should the state or labor unions have a voice in the control?

21 These are questions both of the present and of the future. In thinking about them and working over them it is important to bear in mind the value of scientific method. The discovery of a unit of measurement, a method of measurement, analysis and classification, has made possible great advances in this one small part of the labor problem.

22 Let us get the facts in the labor situation, — all of them. Just as Darwin always recorded all facts which tended to contradict his hypotheses because he knew that unless he did so he would be apt to overlook those facts in order to make his hypotheses triumph, let us also recognize the presence of personal and business interests and bias in ourselves as well as in others. Let us never dodge or shirk the facts. Let us record them so that we and others can study them at any time. Let us measure when means of measurement are obtainable. Let us analyze, weigh, test, and fearlessly experiment. Let us invoke our finest constructive imagination in making our hypotheses. Let us not be dogmatic but humble with our theories, — ready to throw them away if need be when new facts are recognized.

23 Let us last of all never overlook the human instincts. They lie at the heart of our problem. Because of much past neglect in the handling of this question they require the greater emphasis now.

24 It is unquestionably a human trait that every person wants to have some sort of control of the circumstances and direction of his own life and of his work as a part of life. For this reason I believe not only in scientific method and spirit, but I also believe that science must join hands with organized democracy in order to reach any sound solution of the greatest of all our problems. To find the methods and forms of organization through which such a solution may be obtained is the task that lies ahead of us.

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DISCUSSION

ALBERT L. PEARSON (written). In Par. 10 the author refers to illumination of work place and amount of accident risk as two important causes of labor turnover. In designing a lighting system the aim should be to have illumination which will approach, as nearly as possible, daylight efficiency in production. As a result the workmen will be better satisfied and the amount of second-quality work will be reduced. Good lighting is conducive to cleanliness and helps to prevent accidents. Moreover a well-lighted place is attractive, while a dimly or poorly lighted place is just the reverse.

LEWIS S. MAXFIELD (written). As long as any concern persists in maintaining low wages, long hours of service and unsanitary factory conditions, it will experience a large labor turnover because its employees will be continually leaving for factories where the conditions are the reverse of those mentioned. There is no doubt but what the labor problem is what it is today just because we have failed to remember at all times that the laborer is human and should be treated accordingly. It is indeed true that industrial conditions as affecting the worker are changing for the better, but there still remains a considerable field for improvements.

WALTER M. KIDDER (written). The aim of all investigation of the subject under discussion is to disclose the cause for the rate of labor turnover. The best experience of those who have given the subject ample study is that foremen are not likely to ascertain the real reasons for quitting in a large number of cases, or to place them on record uncolored by their own attitude respecting each of them. It is vital to get at the real reason in order to bring it under future control. In some cases it can be learned much more dependably by some other person, for example, by the employment agent, or superintendent, or paymaster, or by some officer or member of the firm who has a faculty for gaining the confidence of employees. In every case of voluntary quitting this step should be taken, even though it adds to the burden of some busy man to listen to the stories he must hear in order to sift out the basic truth of the real cause.

GEORGE H. PERKINS cited a remarkable instance of low turnover in the mill of the Naumkeag Steam Cotton Co. of Salem, Mass., which was destroyed by fire in 1914; twenty months later, shortly

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after starting the rebuilt mills, it was found that 72 per cent of the 1600 old employees were at work in them.

LAWRENCE W. WALLACE said that the manufacturing plant with which he was connected had worked out a comprehensive program for combating the problem of labor turnover, and that in spite of chaotic conditions and unrest the tendency in their labor-turnover curve had been downward. They had obtained much valuable information on the subject from the *Annals* of the American Academy of Political and Social Sciences.

ARTHUR C. JACKSON said that, on the theory that the proper place to draw workers from was the immediate vicinity of the plant, his company was making an industrial census of the community within a radius of one mile from the plant, and advertising the desirability of working within walking distance of home and in a shop that had certain attractions which they felt theirs had. In this way they hoped to reduce the turnover somewhat.

HERBERT M. WILCOX thought that in formulating a constructive program for reducing labor turnover an important factor was recognition of length of service. This should be not only in the form of wage remuneration, but in the conferring of some sort of stripe or medal, so that old employees would hold a more honorable position with the organization than men who had been employed a comparatively short length of time.

CHARLES H. BIGELOW said that the company with which he was connected gave each of their employees a paid-up insurance policy for $500 after they had been in its employ for six months, increasing the amount $100 for each additional year's employment up to a total of $1000. That, he thought, would keep down the labor turnover to some extent because an employee obtained some benefit by staying with the concern, which carried the policy as long as the employee remained with it.

ARTHUR BREWER said that the Bridgeport Brass Company had adopted the scheme of life insurance mentioned by Mr. Bigelow and had also introduced accident and sickness benefits on the basis of the Connecticut compensation law.

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R. F. BURNHAM[1] said that in his plant, employing about 5000 men, in the preceding two years and a half they had taken on over 20,000 men. Recently they had adopted the method of placing all the labor under an employment manager, and if a man sent by him to a foreman did not suit the latter, the man was not discharged, but was put in another department. If he did not fit there, they kept on trying him in various places, and finally when the right groove was found the man stayed. In that way they had reduced their labor turnover fifty per cent.

When a new man came into a department, the foreman was instructed to give him some attention and make him feel that he was a part of the organization. By doing that they made the men content. After two years of service the men received a certain bonus.

Welfare work, visiting nurses, recreation halls, etc., were necessary for the men, especially at the present time when they had a disposition to rove somewhat.

AMBROSE B. DEAN gave interesting details of a part-time method of vocational training successfully adopted in a textile-manufacturing city by the Board of Education, of which he is a member. In many of the mills, however, numbers of men were discovered who were more or less advanced in years and who could not read a blueprint nor understand a simple formula. Attempts made to get them into the regular vocational schools were not successful, owing to their sensitiveness in regard to associating with younger men in school work. This situation was successfully met by organizing a class for the employees of a given mill, and, under the direction of the school authorities, appointing a college-graduate employee of the mill as teacher of the class, the mill owner contributing the time of this teacher and furnishing the classroom.

E. B. SMITH (written). In all cases of productive labor of the skilled class or otherwise, labor turnover has always been found to depend upon one feature: selling the operation or company to the operator. In other words, demonstrate to the producer that each operation is worth while, thereby creating interest and loyalty on his part to the job and company.

The labor turnover is obviously more expensive in the case of experienced hands, who usually have a psychological plus a financial reason for their restlessness. The psychological reason may usually

[1] Hercules Powder Co., Kenvil, N. J.

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be traced back to the company's method of training and schooling their operators. The financial reason lies in the pay envelope. Work coming to an operator from a previous operation in a defective condition is always the start of trouble, and frequently arises from improper training of the operator performing the previous operation. It all resolves itself down to the question of the individual operator under consideration: Was he or she rightly trained?

It has been found that the best way to hold an old operator is to appreciate that he or she is an old operator. The rewards and badges of merit are good. The Christmas envelope of 5 per cent of the yearly wage is also good, but in any case the employee or operator must be contented and satisfied or he will leave.

Our practice has been first to school the operator, then by observation fit the round pegs in the round holes. We have found on a particular operation where ten weeks was ordinarily required, that intensive methods would bring it down to ten days. This means that these intensive methods must be employed if the females are to be fitted for work which the males have been doing.

The males are going to the war and females are taking their places. Therefore it becomes necessary to analyze each operation step by step and cut out the heavy manual part of the work, if possible, by using mechanical conveyors, etc., in order that the female can take it up; then she must be trained and treated so that she will be satisfied. The main thing is to have the operator satisfied with the pay envelope. To get that the operator must be trained well; she must be right and the work coming to the machine must be right.

P. A. McKittrick said that the company with which he was connected built textile machinery, and in one of their plants where about 1600 workers were employed the labor turnover was about 120 per cent, nearly all of it in the first year. If they could hold a man a year they could hold him then as a more or less permanent employee.

During the preceding two years it had been necessary to make many general advances in wages, and in the last advance they adopted the plan of giving each man in their employ up to three months extra pay each month at the rate of 4 per cent of his monthly wages; from three to six months he would get 6 per cent; from six to nine months, 8 per cent; from nine to twelve months, 10 per cent; and in the case of those employed over twelve months, 12 per cent. They had put the plan into operation just at the time when the Liberty Loan was being exploited, and as a result 1300 of their men

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had subscribed about $65,000, using this extra pay to pay for their bonds. They were quite sure the plan would cut down their yearly turnover.

THE AUTHOR, replying to the question whether it would be wiser to leave the problem of control of labor in the hands of employers than to have the state or labor unions share in it, said that he did not think the employers had control of labor turnover now, but as time went on they would get more and more control, and he was personally inclined to think that with the development of employment exchanges, which were very probably coming in this country as they had come in England and in the Continental countries, we might see a method of control of labor turnover for specified districts. That system might be developed by the state, but probably the labor unions would have a voice in its development.

He urged that care be taken to remember that the greater part of labor turnover is not a malady in itself, but is important primarily as a symptom of dissatisfaction or discontent.

By way of addition to Mr. Wallace's remarks, the author said that both the May 1916 and May 1917 issues of the *Annals* of the American Academy of Political and Social Science contained excellent material on methods of reducing turnover. This aspect of the problem, however, was one with which his paper did not attempt to deal.

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No. 1625

ACCIDENT PREVENTION IN THE TEXTILE INDUSTRY

By David S. Beyer, Boston, Mass.
Member of the Society

The author emphasizes the fact that the textile plants have an abnormally high proportion of mechanical accidents. This condition arises from the combination of (1) a relatively large number of machines in operation in textile plants, (2) female and child labor, much of which is non-English-speaking, and (3) an ever-present temptation to clean the machines while they are in operation.

As a means of accident prevention interlocking guards, gear guards, belt guards and belt shifters are discussed fully, and other safety provisions such as the elimination of all protruding set screws, keys, bolts or other dangerous projections from revolving parts, and the guarding of projecting shaft ends, are touched upon.

The process of guarding existing and new machinery is then taken up and a set of safety standards in actual use in a textile plant is given, specifying the safety equipment for gears, sprockets, dangerous projections, pickers, cards, lap machines and doublers, drawing, winding, ring spinning and twisting frames, looms, etc.

THE manager of a steel mill handling several hundred tons of molten metal every day, might think that in comparison with his difficulties the mechanical problems involved in turning out a spool of thread or a bale of cloth would be very simple. A study of conditions in the textile industry, however, would soon convince him that the man in charge of a modern textile plant has some problems which are all his own. Many of these problems come from conditions which have a very direct bearing on accident prevention, notably the following:

2 *Mechanical Exposure.* In the majority of manufacturing industries the number of machines is less than the number of employees. For example, the combined insurance records from a number of states show the following average conditions:

Earthenware Manufacturing	17 machines per hundred employees
Furniture Manufacturing	40 machines per hundred employees
Rubber Goods Manufacturing	60 machines per hundred employees
Printing	67 machines per hundred employees

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers.

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3 In the textile industry, on the other hand, the number of machines usually exceeds, by several times, the number of employees. Sixty-one characteristic cotton mills contained 33,393 employees, and 119,078 machines, or,

Cotton Mills.....357 machines per hundred employees

4 The average cotton mill in Massachusetts has nearly a thousand employees, and several thousand machines. These machines are usually belt-driven and some of them have auxiliary belts in addition to the main driving belt. Most of them have gears at several points on each machine. So it is a simple process of multiplication to see that the exposure points quickly run into the thousands or tens of thousands for a single plant. Thus we can form some idea of what an extensive problem it is to guard completely all the belts and gears in the average cotton mill.

TABLE 1 NUMBER OF EMPLOYEES IN TEXTILE MILLS IN THE UNITED STATES IN 1905

District	Males 16 years and over		Females 16 years and over		Children under 16 years	
	Number	Per cent	Number	Per cent	Number	Per cent
New England States	76,483	49.0	70,113	45.0	9,385	6.0
Middle States	13,852	43.7	15,116	47.6	2,765	8.7
Southern States	54,577	45.5	37,885	31.6	27,538	22.9
Indiana and Other States	806	29.4	1,597	58.3	341	12.3
Total	145,718	46.9	124,711	40.2	40,029	12.9

5 *Kind of Employees.* Another feature of the textile industry that adds to the accident hazard is the fact that such a large percentage of the employees are women and youths. A good idea of conditions in this respect is given by the data in Table 1, taken from one of the U. S. Government publications.[1]

6 These figures were for the year 1905, and it is probable that the number of young persons employed in the cotton mills has been reduced by child-labor laws enacted since that date. It is undoubtedly safe to assume, however, that at least half of all employees in cotton mills are women and children.

7 Women are naturally less mechanically inclined than men and they are not so likely to appreciate the danger of power-driven machinery. Their clothing and long hair are more likely to become

[1] Report of Conditions of Women and Child Wage Earners in the United States.

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entangled in the machinery, thus making the hazard inherently greater for women than for men. The youthful employee also is more likely to be injured through carelessness and as the result of chance taking or horseplay.

8 A large percentage of cotton-mill employees are foreigners, to whom it is difficult to explain fully the hazards of their work. A statement of race distribution in the New England mills (from the Government report mentioned above) shows the following conditions:

American	7.2
English and Irish	22.1
French Canadian	41.8
Italian, Portuguese, Polish and other foreign races	28.9

Thus we see that less than 10 per cent of the employees are American or American-born, although the number who speak English is much larger than this.

9 *Cleaning Machinery.* Another condition which contributes to the accident hazard in the textile industry is the fine lint or fluff which results from many of the operations, and which tends to collect in the form of "fly" over the machinery and gets into the gears and moving parts. While this is not likely to injure the machinery, it brings about a natural tendency on the part of the operator to be constantly cleaning or picking the "fly" out of the machine.

10 Most plants have rules that the machinery shall not be cleaned while it is in operation, but the rules are difficult to enforce. Out of a total of 557 mechanical accidents reported by cotton mills to one insurance company, 88 or about 16 per cent occurred from cleaning while the machinery was in motion. The tendency to do this is enhanced by the fact that the operators are usually paid on a piece-work basis, hence they do not like to lose any product by having the machines shut down for cleaning.

11 Thus we have the combination of (1) an exceptionally large mechanical exposure, (2) female and child labor, much of which is non-English-speaking, and (3) an ever-present temptation to clean the machines while they are in motion. Under these circumstances it is not surprising that mechanical accidents form a large percentage of all accidents occurring in the textile industry. That this is actually the case is shown by the analysis in Table 2 of accidents in Massachusetts, a state which has approximately one-third of all workmen employed in cotton mills in this country. The figures given are taken from the Annual Report of the Industrial Accident Board.

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TABLE 2 CLASSIFICATION OF ACCIDENTS IN MASSACHUSETTS

JULY 1, 1914–JUNE 30, 1915

	No. of Accidents in all industries	Accidents in cotton mills
MECHANICAL ACCIDENTS		
Belting	1039	254
Calenders	137	22
Cranes	328	1
Drills	481	17
Elevators	967	99
Engines	182	18
Extractors	32	4
Eye injuries: Belts, emery wheels, etc.	4373	144
Gears	1087	400
Hoists	654	21
Lathes	869	32
Milling machines	256	4
Miscellaneous	1361	158
Planers	99	.....
Portable tools	70	.....
Presses	1408	8
Saws	1412	40
Shafting (set screws, etc.)	667	199
Vehicles (self-propelled)	1005	8
Wood molders, shapers, etc.	623	13
Machinery peculiar to special industries	8688	1776
Total mechanical	25738	3218
Percentage of grand total	27 per cent	44 per cent
NON-MECHANICAL ACCIDENTS		
Animals	973	13
Asphyxiation and drowning	102	.....
Assault and fighting	136	6
Boiler explosions	40	4
Burns	3339	162
Electricity	451	17
Emery wheels	782	25
Engines	1	18
Excavating	345	2
Explosions (other than boilers)	161	1
Eye injuries: chemical, gage glasses, and molten metal	2261	171
Falling material	1529	62
Falls	8831	646
Glass	1516	134
Hand labor	30974	2012
Illness	186	28
Infection	3581	165
Intoxication	9	1
Miscellaneous	3667	158
Nails	4066	224
Fooling	12	4
Railroad equipment	1007	3
Vehicles (other than self-propelled)	3507	143
Street railways	1051	1
Harmful substances, irritant fluids, etc.	702	21
Total non-mechanical	69229	4021
Percentage of grand total	73 per cent	56 per cent
Grand Total	94967	7239

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12 It will be noted that, while mechanical accidents for all industries of the state were only 27 per cent, numerically, of the total number of accidents reported, mechanical accidents in cotton mills were 44 per cent of the total for this industry, or nearly double the average ratio for the other industries.

13 The additional study in Table 3 of accidents in the thirteen principal industries of Massachusetts, such as boots and shoes, metal-working, electrical supplies, rubber factories, paper mills, and printing establishments, shows that the lost time per thousand employees resulting from the mechanical hazards of belting, shafting and gearing is three times as great in the cotton mills as the average for the whole thirteen industries.

TABLE 3 DAYS LOST TIME FROM INJURY PER 1000 EMPLOYEES

Cause	Thirteen industries	Cotton mills	Ratio
Belting	21.7	43.6	2.0
Shafting	12.4	30.2	2.4
Gearing	21.1	98.2	4.6
Total	55.2	171.9	3.1

14 The results of these studies are corroborative of one another and each of them indicates the important part which accidents from the mechanical hazards play in textile plants.

15 Mechanical accidents as a class are more serious than non-mechanical accidents.[1] While they represent a little less than one-half of all accidents reported in the cotton industry in Massachusetts, it is probable that they are at least three-quarters of the problem from the standpoint of severity of injury.

16 While safety education of employees through the organization of safety committees, safety talks, the posting of safety bulletins and signs, etc., are important in this industry, as in all others, there is probably no other industry where so great weight should be given to mechanical guarding, or where effective guards will produce such important results, as in the textile industry.

[1] See paper by the author presented at the 4th Annual Meeting of the International Association of Industrial Accident Boards, and reprinted in the Weekly Underwriter for September 13, 1917. In one state which kept a separate cost record for these classes, the average mechanical accident cost nearly twice as much as the average non-mechanical accident.

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INTERLOCKING GUARDS

17 The effort to reduce the mechanical accidents in this industry has resulted in the development of a type of guard which is about as nearly "fool-proof" as any mechanical device can be, and that is the so-called interlocking guard. In this form of protection the guard is so arranged that it cannot be removed while the machine is running, and the machine cannot be started until the guard is in place.

18 This result can often be secured by a very simple and inexpensive arrangement; take for example the beater lock shown in

FIG. 1 GUARDS FOR PICKERS

These photographs show an excellent arrangement of guards for belts and chains on pickers. The guards are supported by rods fastened to the framework of the machine, and can be quickly removed, as shown in Fig. 2, by loosening a couple of thumbscrews which secure them to the supports. This permits cleaning the floor underneath the guards without disturbing them, as would be necessary if the guards were supported from the floor. In order to avoid places where "fly" may collect, the guards do not completely enclose the belts and chains, but a transverse section has been placed across each guard, between the two sides of the belt or chain, to prevent danger of a hand being slipped down inside the guard and thus being caught and injured. The projecting end of the beater shaft is protected by a metal cap.

Fig. 3. The beater revolves at high speed and the loss of hands and other serious injuries have resulted from employees putting their hands into it while it is running. To prevent such occurrences a disk is keyed to the beater shaft so that it revolves whenever the beater is in motion. Before the beater cover can be raised a projection on the locking arm used to keep the beater cover closed, must be slipped through an opening in the disk. This can only be done while the disk and shaft are at a standstill, and so long as the locking arm is

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in contact with the disk it prevents the machine being started, which means that the cover must be replaced and the locking arm slipped back over it before the machine can be started up. Similar devices are also applied to various kinds of gear covers, as will be noticed in the other illustrations.

19 This interlocking principle is an effective checkmate to the tendency on the part of the employees to reach into the machinery while it is in operation. The general application of this principle to textile machinery would eliminate many of the accidents which now occur on account of carelessness or thoughtlessness of the employees.

FIG. 2 GUARDS FOR PICKERS

WHEN IS A GEAR GUARD NOT A GUARD?

20 This is a question that has been agitating safety inspectors and plant managers ever since the first gear guard was built. There is a natural desire on the part of everyone to make guards as simple and inexpensive as possible. Unfortunately, this perfectly legitimate desire has resulted in two types of guards for gears which are so ineffective that they have tended to discredit guarding to a certain extent, because accidents still occur after the so-called guards are installed. One of these types is a band over the face of the gear, following more or less closely the outline of the gear, but leaving the most dangerous part, that is, the mesh point, exposed sufficiently to admit a finger or even a hand. Another method is to provide

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a guard which protects the mesh point but which is not carried around the periphery of the gear, and thus forms a shearing action between the teeth of the gear and the edge of the guard at the point where the teeth pass underneath the guard.

21 Many of the pioneer concerns in the safety movement, such as the U. S. Steel Corporation, started out by installing gear guards of this type but found that they did not eliminate the accidents and later changed them to guards completely enclosing the gears. There are many partial gear guards in the textile industry today, and they sometimes contribute to accident occurrence from the false sense

FIG. 3 INTERLOCKING DEVICE FOR BEATER COVER AND DOOR OVER DIRT GRID (PAT.)

In order to open the beater bonnet or the door, a projection on the locking lever (shown in white) must be slipped through the disk on the beater shaft. Obviously this can only be done while the machine is at a standstill. In order to start up the machine again, the locking lever must be slipped out of engagement with the disk, which insures the bonnet and door being closed before the machine is started.

of security they inspire. The following cases taken from actual reports from textile mills may serve as examples of such accidents:

Accident 1809, "Cleaning cover over spindle gears, forefinger of right hand caught between cover and gear."

Accident 3395, "Cleaning frame in motion, in some manner got finger under guard."

Accident 3409, "Was cleaning cover of gears and put hand under cover, finger was crushed to first joint."

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Accident 12364, "Another man pushed him against roving frame and he put out his hand to keep from falling and put fingers through opening in gear cage on end of frame and came in contact with gear."

Accident 15992, "She caught her finger between gear and gear guard; the terminal phalanx was fractured at middle."

22 An analysis of 550 textile-machine accidents reported consecutively to an insurance company showed that 88 of these accidents or about 16 per cent were from gearing; more than a third of the gear accidents were due to cleaning the machinery while in motion.

FIG. 4 BELT SHIFTER FOR CARDS

This shifter can be installed by simply securing it to the circular flange above the pulley by means of one or two set screws. It only requires a few seconds to loosen these set screws and slip off the shifter, as shown in Fig. 2, when it is necessary to reverse the belt for grinding.

23 Surely if there is any industry where complete guarding of gears is necessary, it is the textile industry, on account of the prevalence of accidents resulting from cleaning running machines. It is not practicable to apply the interlocking principle to all gearing on textile machinery, but it is practicable to fully enclose the gears, and where the guards are not interlocked they should be firmly fixed in position by cap bolts or other means that make it difficult for the operatives to remove them quickly and tend to restrict their removal to properly authorized mechanics.

24 It will be noted from the list of Massachusetts accidents already given that out of a total of 1087 gear accidents occurring

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in one year the cotton mills contributed 400; in addition the woolen and worsted mills had 236. Thus we see that cotton and woolen mills were responsible for considerably more than half the total number of gear accidents, although they only employed about one-quarter of the workmen engaged in manufacturing industries in the state.

BELT GUARDS

25 There were 254 accidents from belting in Massachusetts cotton mills during one year, and 113 accidents in woolen mills, or a total of 367 for the two industries; this shows that belt guards are also important for textile machinery.

FIG. 5 BELT SHIFTER FOR CARDS

26 A good many textile machines, such as roving, spinning and twisting frames have an outboard bearing, supported by a framework around the pulley, that tends to keep employees away from the pulley and offers a certain degree of protection. In addition, these machines are commonly provided with belt shifters, and where the shifter comes down close to the point of contact between the belt and pulley it considerably reduces the chance of any one being caught at this point, where most of the serious belt accidents occur.

27 Several manufacturers of these machines have provided an excellent guard, consisting merely of a semicircular disk casting or plate which is fastened to the outboard bearing of the machine.

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This guard only extends a few inches above the contact point between the belt and pulley, and does not guard the upper part of the belt to the height which is commonly prescribed in insurance and other mechanical standards for safeguards. However, in conjunction with the partial protection which is afforded by the outboard bearing and the shifter, it would seem that this type of guard would elimi-

FIG. 6 BELT GUARD ON SPOOLER

This shows a belt guard which has been developed by one of the machinery builders. This is a simple and inexpensive type of guard, but taken in conjunction with the outboard bearing and belt shifter it gives quite a good degree of protection.

nate probably 95 per cent of the hazard, and would give adequate protection for the belts of these machines. It can be furnished by the builders in a standard form and at slight cost, and as it would prevent accidents from causes such as a loose skirt blowing out and being caught between the belt and pulley or persons slipping or tripping and having their hands caught at this point, it would seem to be well worth installing generally.

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28 For other types of machines it is usually impossible for the machinery manufacturer to provide belt guards as an integral part of the machine, on account of the fact that the driving belts lead off at various angles which can only be determined by the local arrangement of each plant. Under such conditions it is necessary for the belt guards to be installed at the plant after the machinery is in place.

BELT SHIFTERS

29 Some types of textile machinery, such as roving and spinning frames, have long been equipped with belt shifters as an operating

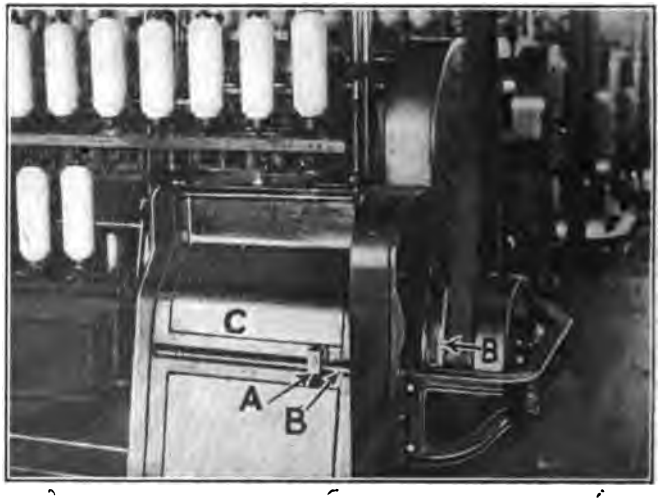

FIG. 7 INTERLOCKING GUARD FOR HEAD GEARING OF ROVING FRAME

Block *A* on rod *B* which is attached to the belt shifter, projects over gear cover *C* when the belt is on the tight pulley (Fig. 7), thus preventing the cover being opened while the machine is running. When the shifter is moved so as to throw the belt on the loose pulley (Fig. 2) and stop the machine, cover *C* will clear block *A* and can then be opened. The edge of the open cover, however, interferes with block *A* so that the belt cannot be shifted to the tight pulley again until the cover has been closed.

necessity, since the operators need to shut down the machine at some distance from the driving belt. Other machines, such as cards, are commonly found without shifters. There has been a notion generally prevalent among mill owners, that it was impracticable to apply belt shifters to cards on account of the grinding operation which requires the belt to be reversed. Shifters which are thoroughly practical in operation have been developed, however, and cards, as well as other textile machines, should be so equipped.

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OTHER SAFETY PROVISIONS

30 There are various additional forms of mechanical protection which are desirable for textile machinery, such as the elimination of all protruding set screws, keys, bolts or other dangerous projections from revolving parts, and the guarding of projecting shaft ends. There are crushing or shearing actions formed in some machines such as mule spinning frames, which should be protected, as should also the rope drives on mule frames.

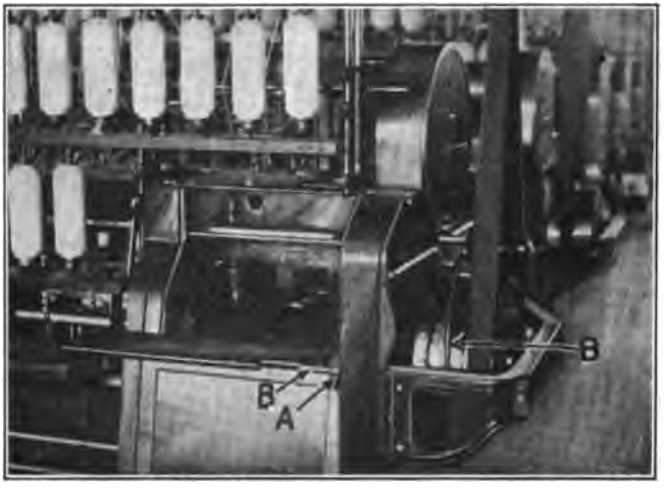

FIG. 8 INTERLOCKING GUARD FOR HEAD GEARING OF ROVING FRAME

Gear cover *C* must be swung upward in order to open it. A finger *E* fastened to this cover will not clear stop *A*, attached to shifter rod *D*, when the belt is on the tight pulley and the machine is running, so the guard cannot be opened. When the belt is shifted to the loose pulley, however, stop *A* moves to position *B* where it clears finger *E* and permits the guard to be opened. In the open position stop *B* interferes with finger *E* and prevents the belt being shifted to the tight pulley until the gear cover has been closed.

31 Many eye injuries have been caused by shuttles flying from looms, and shuttle guards are accordingly important for weaving equipment.

32 Steam-heated drums or cylinders of slashers, calenders, etc., should be provided with relief valves, and a reducing valve with pressure gage and safety valve on the low-pressure side of the line are important items of safety equipment for the steam line supplying auxiliaries of this kind.

33 There were 1776 accidents in one year in Massachusetts caused by machinery peculiar to the cotton mills, and 903 by

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machinery peculiar to the woolen and worsted mills, making a total of 2679 for the machinery used in these two industries.

34 It is intended to limit the scope of this paper to mechanical forms of protection, but passing attention may be directed to the importance of safe clothing for female operatives, such as the use of caps or other methods of dressing the hair which will reduce the danger of its being caught in the machinery. Possibly we will profit by the experience of English munition factories and replace the flowing skirt with overalls in the textile industry. This plan is now actually being tried in some American plants.

FIG. 9 INTERLOCKING GUARD FOR DRAFT GEARS OF ROVING FRAME

This shows one of the interlocking devices (the parts of which are white in the picture) developed by a machinery builder for application to his equipment. It is so arranged that the door cannot be opened while the machine is running, and the machine cannot be started until the door has been closed.

GUARDING EXISTING EQUIPMENT

35 There are usually many machines in each textile plant which are duplicates of one another, so that the pattern for one guard may apply to several hundred machines. Where the guards are made by the manufacturer and the expense of designing guards and making patterns, etc., can thus be distributed over a number of mills, the cost can be reduced to about the lowest possible minimum.

36 In spite of this condition, however, when we take into consideration the fact that several thousand guards may be required to fully protect the machinery in a single plant, it is evident that the

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guarding of existing machinery must necessarily be carried along gradually so as to distribute the labor and expense over a period of years.

GUARDING NEW EQUIPMENT

37 New machinery is constantly being installed, however, and at the present time much of this machinery is going in in an unguarded or partially guarded state, even though the machine builders have developed guards that are simple and effective for most of the dangerous machinery, and will furnish these guards for new equipment at little or no increased cost. This is an inefficient way of handling the matter, as it is often difficult for the mills to design satisfactory

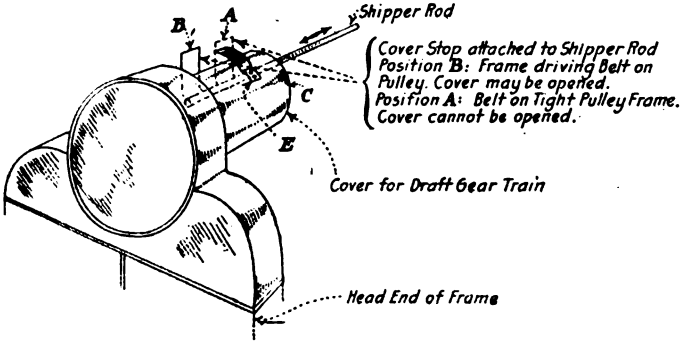

FIG. 10 INTERLOCKING GUARD FOR DRAFT GEARS OF ROVING FRAME

The guard shown at the right of this picture prevents danger of a hand being caught and injured, as might occur were the machine unguarded as shown on the left.

guards after the machinery has been installed, and the cost of the latter method is considerably greater. Worst of all from the safety standpoint, workmen are likely to be injured on the unguarded machinery before it can be protected.

38 Probably the installation of unguarded machines is due more than anything else to the lack of definite safety standards in this country for textile machinery. As matters stand at present the different textile plants have little opportunity to find out what are effective and practical guards which they could use in ordering new machinery. The machinery builder is also in a quandary, on account of the varying requirements of different states and of different plants. If one builder attempts to furnish complete safeguards for his equipment he is likely to be underbid by a competitor who economizes on cost by omitting the guards.

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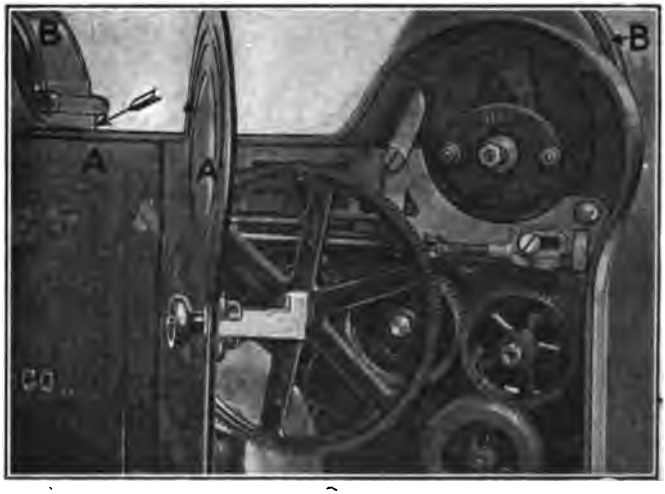

FIG. 11 INTERLOCKING DEVICE FOR DOOR PROTECTING HEAD GEARING OF SPINNING FRAMES (PAT.)

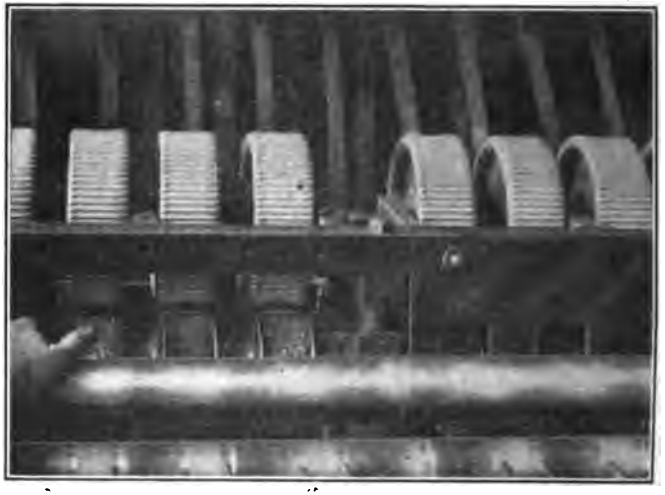

FIG. 12 GUARD FOR GILLS OF GUNNY ROVING FRAMES

SAFETY STANDARDS FOR TEXTILE MACHINERY

39 Probably the most effective step toward overcoming these difficulties would be the preparation of definite and authoritative safety standards which could be used by the factory manager in

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ordering new equipment and by the builder in designing his machinery. If such standards were prepared and given wide general publicity they would undoubtedly be followed for most of the future installations.

40 It would seem that this might be an excellent line of effort for the Sub-Committee on Protection of Industrial Workers of the Society, or for a special committee which might be appointed in the Society. The textile section of the National Safety Council at its Annual Congress in New York of this year went on record in favor

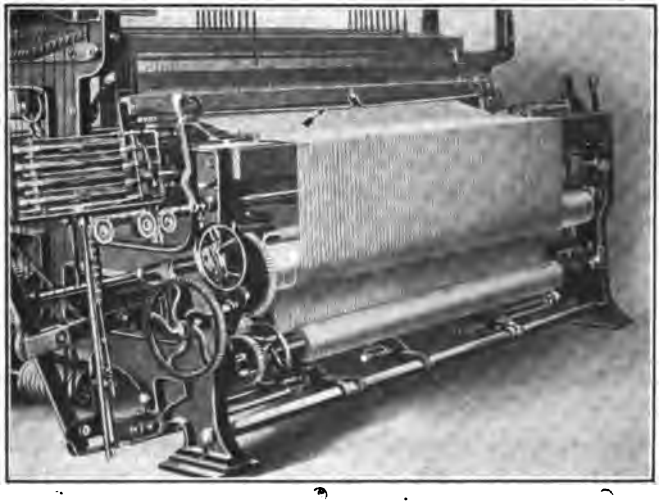

FIG. 13 SHUTTLE GUARD ON LOOM

This illustrates one of the standard shuttle guards used on looms. (It also shows a number of unguarded gears which are quite prevalent on this machinery.)

of such standards, and voted to appoint a committee which would coöperate with any others interested in drawing up safety standards for the textile industry.

41 Much work in the way of developing satisfactory safety devices for this machinery has already been done, and provisions such as the following, each one of which has been put into practical use by one or more plants, might well be included in these standards:

GENERAL STANDARDS FOR ALL TEXTILE MACHINES

1 All gears and sprockets exposed to contact shall be completely enclosed, or have a band guard around the face of the gear or sprocket with side flanges extending inward beyond root of teeth, of such design and arrangement

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that a finger cannot project through, over, around, or underneath the guard and be caught in mesh point of gears or contact point of chain and sprocket.

2 All dangerous projections on revolving shafting such as protruding set screws, keys, bolts, and couplings, shall be made flush with the surface or effectively guarded in such a manner as will prevent their catching clothing of persons which may come in contact with them. Projecting ends of beater shafts shall be encased or otherwise effectively guarded.

3 Driving belts shall be equipped with mechanical shifters.

ADDITIONAL STANDARDS FOR CERTAIN TEXTILE MACHINES

Pickers. All beater covers and doors which can be reached while the machine is running, shall be equipped with interlocking devices which prevent their being opened while the machine is in operation and the machine being started until the covers are in place.

Cards. Cylinder covers or doors shall be equipped with interlocking devices which prevent their being opened while the machine is in operation and the machine being started until the covers are in place.

Lap Machines and Doublers. These machines shall be provided with interlocking guards which will prevent the operator from coming in contact with the in-running rolls while they are in motion.

Drawing, Winding, Ring Spinning and Twisting Frames, Etc. Covers or doors giving access to head-end gearing of these machines shall be equipped with interlocking devices which prevent their being opened while the machine is in operation or the machine being started until the covers are in place. A guard shall be placed in front of the driving pulley which will effectively guard the point of contact between the belt and pulley.[1]

Looms. Looms shall be provided with effective shuttle guards.

PROTECTION AGAINST INCREASING ACCIDENT COST

42 Two years ago the rate for compensation insurance on cotton mills in Massachusetts was 45 cents per hundred dollars of payroll, and it was similarly low in other states. This rate was found to be inadequate to cover the accident cost even at that time, and since then two or three legislative changes increasing the benefits to employees have been made. As a result the insurance rate for cotton mills has about doubled, and it is likely to keep on increasing from year to year as the benefits of the compensation acts are further extended by subsequent legislatures.

43 The accident records, as already mentioned, show that mechanical accidents are the most serious and that the textile plants have an abnormally high proportion of these accidents. So long as this condition exists the cost of compensation insurance for the

[1] Belt guards should also be provided for other machines, but they can usually be furnished more advantageously by the purchaser than by the machinery builder.

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textile industry will be high; but there is one effective way to reduce this cost, and that is by reducing the accidents. Many employers have already eliminated 50 per cent, 60 per cent and even 80 per cent of the injuries to their employees.

44 No employer wants to see the people who work for him needlessly injured; this can be taken as a matter of course. It is a new fact to most business men, however, that it is possible, through the prevention of injuries, to cut in two an important item of manufacturing cost. When this is made clear, accident prevention immediately commands the attention of both the engineer and the manager, as a matter of plant efficiency.

DISCUSSION

JOHN W. UPP (written). Few realize the vast number of minor accidents that occur in our workshops and factories, or have any adequate conception of the aggregate cost of such accidents until they make up their yearly reports or look at classifications of accidents such as are presented in Table 2 of the paper. As we gain in experience we find that the majority of these accidents are preventable if we install safety appliances and then see that these appliances are guarded and kept in place after the first installation.

We are very much pleased to find that the author recommends those machine guards which are interlocking, and that they compel the operators to use them. Gears are indispensable on many machines and must frequently be used in exposed positions, but they can and should be provided with adequate guards. Belts, fortunately, are beginning to give way to direct drive, but there are still enough of them in use to warrant special attention being given to guarding, for they are even more hazardous to the woman worker than gears.

In the various factories in which the writer is interested we have found our safety-committee work the most profitable single undertaking with which we deal. We give the committees complete authority; they can discipline those operators who jeopardize their own interests or those of others when they remove guards, and they analyze each accident report and do not dispose of it until they have indicated a means of preventing similar accidents in the future.

GEORGE R. WADLEIGH said that in regard to the belting, particularly in the spinning room, which is equipped with what is known as the Lockwood, Greene drive, it seemed impossible in that case to

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run a belt guard from the floor up to a height of 6 ft. This, in his opinion, was more or less unnecessary, but at the same time it was the law in some of the states. Another requirement in several of the states was a screen around large belts. In their records of accidents going back five years, in a number of textile mills they had only one case of any one being injured by falling against a main driving belt.

W. G. DUNCAN said that manufacturers had had a great deal of trouble, not only in regard to the lack of uniformity of standards between one state and another, but between the various whims of the different state inspectors. He thought also that the legislatures had made a mistake in passing laws which were entirely too mandatory and which left to the safety department of the state or the chief engineers and inspectors no room for the exercise of any judgment whatever. His company had been very much annoyed in putting on a set of guards which were satisfactory to the state inspectors one year, and then being told the next year that they were worse than useless and must be replaced by something else. It seemed to him that the first step in this matter was to bring about a standardization of safety devices.

P. A. MCKITTRICK emphasized the need for standards, stating that his company sold machinery to manufacturers in nearly every state in the Union and practically every country in the world, and that it was necessary for them to have very many sets of patterns—what was good and sufficient for one was not for another. This burden was entirely on the machinery builder, because his company had never succeeded in getting any recompense for the additional work.

RICHARD B. GREGG[1] asked the author whether there were any figures which showed the distribution of accidents throughout the day and week; that was to say, were there more accidents the first thing on Monday morning than there were the first thing, say, on Thursday morning? Were there any more accidents at the end of the working period along at 11.30 or 12 o'clock, or 5.30 or 6 o'clock, than there were at other times in the day? He thought that was sometimes an element in the human factor which was overlooked, as sometimes we ascribed accidents to sheer carelessness which were really due to fatigue of the operator.

[1] 814 Flatiron Bldg., New York City.

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WILLIAM D. HARTSHORNE said in regard to the time of day accidents occurred, that for some 10 or 15 years while he was connected with the Arlington Mills, at Lawrence, Mass., there was kept an accurate account of every accident, the hour at which it occurred, the cause of it, and every detail about it, and he would say that there was no question but what there was a material difference in the nature of the accidents which occurred at different hours of the day, and that there were many accidents which occurred on Monday morning which, taken in connection with the circumstances which surrounded them, were certainly well worthy of special consideration.

S. C. COEY said that he had made somewhat of a study of the time of day of accidents in the steel industry, and found that in the case of the Youngstown Sheet & Tube Co. the greatest number came along in the morning hours, about 10.30, and that thereafter another peak in the accidents occurred in the afternoon. The peculiar thing about this time of greatest accidents was the fact that it was at the same hour as the peak in the power curve, showing that the rate of doing work in the plant and the number of accidents had a certain definite relation. He had been connected with the Celluloid Company, of Newark, for the last few months and had had a curve drawn up along the same lines, which showed the same general results in that industry as in the steel industry.

ALLAN D. RISTEEN said that in making reports of accidents, where the hour was not recorded at once there was a certain psychological factor that influenced the man who was filling out the blank not to set the hour at opening or closing time, but somewhere in between. He did not mean to say that that was wholly responsible for the peaks in the morning and afternoon curves, but desired to call attention to the fact that there was certainly an influence of that kind which tended to emphasize the peaks, and which should be considered when statistics were being studied.

THE AUTHOR, in closing, said that he desired to speak a word in behalf of the machinery manufacturer, and that was this: That the man who used the machinery was paying the money, and he was really the one who held the key to the situation. They had found in the U. S. Steel Corporation that when they got out definite specifications for new machinery showing what they wanted, the manufacturer gave it to them, but until they adopted that plan they had quite a

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variety of results. That would be taken care of by the definite standards suggested in the paper — the machinery builder would know what he had to give and the employer would be assisted in securing the best.

Replying to Mr. Wadleigh, he said that he had never been in sympathy with the 6- or 7-ft. height specified for the belt guard in some cases. He had asked a number of safety engineers if they had ever known of an accident in a case of a belt guard which was run to a height of 3 ft. 6 in. from the floor, and had never been able to find a record of such an accident which could have been prevented by the higher guard. A committee of engineers of the insurance companies he was connected with was working on this matter, and had called a conference to which representatives from the New York, Massachusetts, Pennsylvania, New Jersey, Wisconsin and other labor departments were invited, in an effort to get uniform standards adopted in all these states which would be practicable and would not go too far, as it was now felt some of these standards did. He thought it would be of great value to the employers in the different states and quite a step forward if this could be done.

The question of an overhead belt guard had been raised, and he knew of one or two cases of serious injury or death from the breaking of overhead belts. That did not happen often in any one plant, but where there were several thousand plants located in each state a number of accidents occurred every year, and he thought it was desirable to guard 12-in. or wider belts — when they were fast-running belts.

The question of standardization was largely up to the insurance inspector and state inspectors in getting uniform results, but he thought the Society could exercise an excellent influence in bringing about a more general uniformity in standardization.

The question of the time of day at which accidents occurred had been pretty well discussed. He had made a number of such analyses and studied a good many others, and found that almost invariably both in this country and abroad the accident rate increased gradually until within about an hour of the end of the turn, both in the forenoon and afternoon, and then dropped off. There it seemed that the employees got their second wind and began to pick up a little and look toward the closing of the day. That was such a constant condition that he hardly thought it could be due to the makeup of the report, and he thought it did represent the psychological and physical condition of the employee. In regard to a

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relation between the peak of the load and the frequency of accidents, the load in the textile industry was apt to be pretty even, so that there was not the variation due to the human factor that would be found, say, in the steel industry.

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No. 1626

THE MOISTURE CONTENT OF TEXTILES AND SOME OF ITS EFFECTS

By William D. Hartshorne, Methuen, Mass.
Member of the Society

With materials as valuable as silk, wool, flax and cotton, and such of their products as are sold by weight, the actual weighing of the moisture they may happen to contain at the time of sale is of evident importance to both buyer and seller, when it is once understood what slight changes of circumstances can cause a loss or gain in weight involving thousands of dollars in many every-day transactions.

When such materials are bought and sold on a conditioned weight basis, the standard dry weight of a shipment is obtained, upon which certain percentages of "regain" or added weight are allowed, varying with the hygroscopic capacity of each class of material. The author, after an investigation covering a period of over twenty years, has developed a set of laws governing regain in cotton and worsted, which are set forth in the paper with particulars regarding their derivation, and are accompanied by numerous charts and tables for facilitating calculations.

THE investigations recorded in this paper were begun in a comparatively crude way for a strictly limited commercial purpose, but it soon became apparent that a fundamental study of the subject of moisture content of materials was needed in all branches of textile manufacture. Indeed, this had become evident to the writer in his still earlier attempts to produce and maintain good spinning conditions by temperature and humidity control for a single worsted spinning frame in a small closed room. Dog-day weather in summer and electrical effects in winter were equally important to combat, and in an effort to offset the latter, dog-day results were easily reproduced in midwinter.

2 The relative equilibrium of the moisture content of the fiber to the surrounding atmosphere was evidently the key to at least one phase of the problem. When the laws of equilibrium relating to weight had been definitely established, and when, as relating to dimensions, the fact had been demonstrated that the effect of ab

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sorbing moisture upon both wool and cotton fibers was not only to swell them but to lengthen them, rather than shorten them, as had sometimes been erroneously contended, one of the most important conditions for good or bad work at the spinning frame became evident and demonstrable.

3 The smoothness and evenness of a thread are dependent upon the relation of its moisture content to the surrounding atmosphere at the time of spinning; and many of the hitherto puzzling defects in a finished fabric are explainable, and the remedy or method of prevention rendered obvious, as soon as the correct relationship of these facts to weaving and fabric-finishing conditions is apprehended.

4 Moreover, the effects of moisture content upon strength and elasticity are not less important, both in manufacturing processes and the commercial use of textiles. This may be illustrated by the comparatively recent observation that the strength of the standard make of cotton tire fabric (and other cotton fabrics have been shown to follow a similar though not identical law) increases approximately 7 per cent for each 1 per cent increase in moisture content, reckoned from the bone-dry state, up to (curve not yet accurately determined) approximately 8 to 8½ per cent.

5 The most significant effects of moisture content upon textiles may be classified under three general heads:

I Weight
II Dimensions
III Strength and Elasticity.

6 Under these respective heads, among the different textile materials there is great diversity of effect, and as a consequence a great divergency in unverified opinion. Research has, it is true, established beyond reasonable controversy some of the essential data requisite for further study, and commercial precedent has recognized the necessity for standards in measuring some of these effects; but it is from the economic advance in the manufacture and the skilled usage of such materials that the greatest demand for accurate knowledge is gradually coming.

7 The most obvious of these effects is weight, and to this factor the present paper is mainly devoted.

8 To conditions causing changes in weight much more effective study has been given than to those causing changes in dimensions

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or strength and elasticity. These latter are complicated by other factors, such as twist or weave, which tend to increase or diminish the ordinary effects of moisture.

EFFECT OF MOISTURE CONTENT ON WEIGHT

9 In measuring weight, long before any exact causal relationship had been established between the various factors, certain standards of moisture content for the principal textile materials, such as silk, wool, cotton and flax and their manufactured products, had been established by custom and to some extent sanctioned by law in the principal continental markets and in England as a basis for purchase and sale.

10 Variations in weight between different materials due to their individual hygroscopic properties as affected by atmospheric changes alone were thus recognized, and a standard basis for figuring the standard allowances agreed upon was also adopted and with few exceptions has been steadily adhered to.[1] This standard basis was obtained by determining the average loss in moisture of a series of representative samples from the lot of material in question by drying them in a proper oven at a temperature of 221 to 230 deg. fahr. until they ceased to lose weight, or until the rate of loss had reached a prescribed minimum.[2]

11 The standard allowances made upon this "standard" dry basis of weight (sometimes called the bone-dry or the absolutely dry basis) are commercially called "regains," a nomenclature liable to misconception and misapplication which it is important at the outset to avoid both in practical use and theoretical study. The hygroscopic capacity and other properties of both wool and cotton, for instance, are well known to be materially affected both by the

[1] Notes on Sampling and Testing (1913 edition), issued by the Manchester Chamber of Commerce Testing House, gives a fairly good summary of what might be called the most general standards used for textile materials. "The various standards of moisture were first authoritatively fixed at the 'International Congress for the Establishment of a Uniform System of Numbering Yarn,' held at Turin in October, 1875."

[2] Notes on Sampling and Testing, pp. 15–16: "The temperature adopted by the Manchester Testing House for drying cotton is 212 deg. fahr. It may at once be said that this temperature is some 10 to 15 deg. lower than that used at the large continental conditioning houses during the last half century, and it is not clear how the testing house came to adopt the lower temperature of 212 deg."

The increased loss in drying cotton at 220 to 230 deg., if properly conducted, is, as given by the same authority, less than ½ of 1 per cent.

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temperature at which they are dried and the length of exposure to a drying and oxidizing atmosphere.

12 In the case of cotton in its natural state as it comes from the bale, it has been observed that mere exposure to the air for some months materially affects the hygroscopic capacity of the mass. This is in part no doubt due to the presence of extraneous materials, such as "leaf" from the cotton plant, but also probably to the gradual hardening of the waterproof coating of waxlike material with which the cotton fiber is covered; and which, though itself non-nitrogenous and non-hygroscopic, appears to be incorporated with or to cover another coating both nitrogenous and more hygroscopic than cotton itself.

13 The processes of mill preparation, especially combing, eliminate any appreciable effect of "leaf" upon moisture capacity, but the "pectose" matters, as the coverings are sometimes termed, remain with varying capacities for change until removed in the process of boiling off for dyeing, bleaching or mercerizing. Each of these processes has its own important effect upon the hygroscopic capacity of the manufactured product which need not be considered here.

14 In the case of wool as it comes from the sheep's back, there is also a natural and very complex coating. Part of this, the true wool grease, resembles in some respects the waxlike part of the cotton coating, but in its undecomposed state is a complex fatty acid compound with various bases, known chemically as chlorestin and its isoforms, forming fat-like bodies of various melting points whose function on the sheep is to keep the individual wool fibers lubricated. These fat-like bodies, or "esters" as they are sometimes called, differ from mutton fat or beef fat in not having glycerine as a base and being much more difficult to saponify with either caustic soda or caustic potash into true soluble soaps. Nevertheless they readily emulsify with soaps and alkalis and may be thus removed, as in the ordinary soap-scouring method of wool washing. Another distinct portion, left on the wool when the true grease is removed by petroleum ether or naphtha, is also a complex compound of fatty acids (similar to those found in the grease) with almost pure potash, forming natural soaps of excellent detergent properties and being sufficient in amount in most wools to fully cleanse them without the use of any other soap after the grease proper has been

[1] Robert E. Naumburg, in Trans. National Association of Cotton Manufacturers, vol. 100 (1916), p. 385.

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separately removed. This "sweaty" matter is very hygroscopic — much more so than the wool itself; and may be the occasion of material differences in judgment as to the probable shrinkage of a given lot of wool examined under different circumstances.

15 With materials as valuable as silk, wool and cotton and such of their products as are sold by weight, the actual weighing of the water they may happen to contain at the time of sale is of evident importance to both buyer and seller when it is once understood what slight changes of circumstances can cause a loss or gain in weight involving thousands of dollars in many everyday transactions.

16 The standard condition upon which worsted yarn and tops combed without oil have long been bought and sold in England and on the Continent allows 18¼ per cent regain or added weight to the standard dry-weight condition.[1] The standard for silk is 11 per cent and for cotton is 8½ per cent. Until recently no standards except for silk, which is the same the world over, had been generally recognized in the United States.[2]

17 Theoretically, it makes no difference whether the standard condition of regain be assumed at one figure or another provided that the actual condition is known and that some standard has been agreed upon between buyer and seller. Practically, however, it is desirable that the standard condition be somewhere near the average expected for the country in which the transaction takes place, and that at the time of delivery the material shall in its whole mass be as near as may be in this standard condition. If the latter were not so, it might be difficult to allow accurately, to the satisfaction

[1] For tops combed in oil the Bradford, England, standard is 19 per cent moisture regain. This seems a curious anomaly, but is explained by the manager of the Bradford Conditioning House as simply a trade custom of long standing.

[2] The following resolution was unanimously adopted at the Annual Meeting, April 1916, of the National Association of Cotton Manufacturers. See Trans., vol. 100, p. 416:

RESOLVED, That the National Association of Cotton Manufacturers, in convention assembled, approve the adoption in this country of 8½ per cent moisture content reckoned on the so-called bone-dry or standard dry weight, for all commercial transactions in baled cotton and cotton yarns, in harmony with prevailing international custom.

That in the absence of any sufficient reason to the contrary (which there may be in some cases), this state of moisture content is approved for all ordinary quality and quantity tests and measurements, from the cotton fiber to the cotton fabric.

That in any transaction where a different condition is by custom or agreement preferred, that condition should be carefully specified within practical limits.

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of both parties, for the changes in weight which might easily take place in transit or upon exposure to conditions greatly different from those under which the material was originally packed.

18 It was the recognition of these commercial features relating to weight which led the writer to derive and compile the data in this paper covering a period of over twenty years.

CORROBORATION OF 15 PER CENT REGAIN FOR WORSTED

19 The importation of worsted yarns and tops into this country under foreign exporting conditions, owing to the loss of weight sustained upon storage here, had given the impression that there must be at least 2 or 3 per cent difference in weight due to climatic reasons.

20 It was important, therefore, in developing the new American industry of combing tops for the trade, to adopt a standard believed to be safe for this country. This was put at the arbitrary figure of 15 per cent regain, an amount easy to calculate and also within expected limits. It seemed best, however, to determine with some degree of certainty how near this figure was to the average natural condition corresponding to some one locality, such as Lawrence, Mass.

21 With this object in view, a skein of worsted yarn, 2/42 Australian, combed in oil and spun on the Bradford system, was prepared whose absolute or rather "standard" dry weight was carefully determined by weighing and testing other skeins of the same material under exactly like conditions. This method of using substitute skeins was adopted to avoid the known effects of heat in changing the hygroscopic property of wool and other fibers.[1]

[1] In a discussion of this subject before the New England Cotton Manufacturers' Association, vol. 79, p. 221, the author emphasizes the importance of this point to textile manufacturers in their ordinary business of drying fabrics, by stating: "When wool — and the same is true of cotton, though perhaps to a less degree — has been once thoroughly dried at any such temperature as is necessary to bring the material to what is called the absolutely dry state, there is a decided loss of hygroscopic property; and a skein of yarn so treated does not naturally return again to the same moisture state that a similar skein would under like conditions have reached, which had not been so overheated. In the case of drying worsted fabrics particularly, it is extremely important, if you wish to retain their natural hygroscopic property, not to overheat them in the drying process. It is extremely necessary also, in top manufacturing, not to overheat worsted stock at any time in the process of manufacture, or you will seriously injure its working property as well as its hygroscopic property."

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22 This skein was then hung up in an open shed, protected from sun and rain but having good ventilation so that it could be considered as fairly representing the changes due to exterior atmospheric conditions uncomplicated by sunshine or rain. Its weight was then carefully taken and recorded ten times a day, at approximately equal intervals for a period of one year, and for every day in the year except Sundays and holidays. Records were also kept of the temperature and relative humidity, as obtained from the readings of a set of wet- and dry-bulb thermometers located within a few

TABLE 1 VARIATIONS IN WEIGHT OF SKEIN OF WORSTED FOR ONE YEAR

	Lowest day		Highest day		Lowest observation		Highest observation		Greatest difference in 24 hours	
	Per cent	Date	Per cent	Date	Per cent	Date	Per cent	Date.	Per cent	Date
May	11.60	17th	21.50	27th	9.7	17th	22.0	6th and 27th	8.2	6th to 7th
June	13.01	19th	25.92	29th	10.7	14th	27.5	28th	10.0	5th to 6th
July	14.95	25th	23.96	17th	12.9	3rd	26.6	1st	9.1	1st to 2d
August	14.45	9th	22.00	13th	12.6	21st	22.9	13th	8.7	7th to 8th
September	12.19	24th	23.27	11th	11.5	24th	25.9	26th	12.1	26th to 27th
October	13.61	18th	22.71	8th	12.2	18th	28.0	14th	11.3	28th to 29th
November	15.59	22d	31.77	26th	14.1	4th	35.1	26th	19.1	26th to 27th
December	15.41	27th	30.70	2d	13.0	27th	33.7	2d	16.1	2d to 3d
January	13.54	4th	34.26	25th	13.0	29th	34.9	25th	15.1	24th to 25th
February	12.79	25th	29.92	6th	12.2	25th	33.4	6th	17.3	6th to 7th
March	11.93	27th	27.30	2d	10.2	27th	28.8	20th	16.4	30th to 31st
April	9.03	30th	21.89	2d	7.3	30th	24.0	2d	12.2	1st to 2d

General average (by the month) for the year, 17.45 per cent.
Lowest average periods, (April) 14.15 and (May) 14.86 per cent.
Highest average periods, (November) 22.02 and (December) 19.28 per cent.
Lowest observation (April 30), 7.3 per cent.
Highest observation (November 26), 35.1 per cent.

feet of this skein and taken at the time of each weighing, except for a short time in winter, when the humidity observations were omitted owing to the difficulty of obtaining them accurately at low temperatures.

23 Table 1 shows the variations in weight of this skein, which were remarkable, ranging from a little over 7 per cent to as high as 35 per cent on the calculated dry weight. There were occasional variations of 15 or even 19 per cent in 24 hours.

24 Aside from the temporary extreme changes, there seemed to be a fairly regular diurnal variation, the weight being generally

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greater in the morning and less in the afternoon. This may perhaps be best exemplified by Fig. 1, representing the average of the daily weighings of this skein for each respective hour named thereon throughout the year. The weights are given on the basis of 100 parts for the absolutely dry weight, so that the regain percentage is at once shown. Fig. 1 shows that on the average there was, for that year at least and for that skein, a difference of about 2¼ per cent between 7:30 a.m. and 3:30 p.m. A typical day is shown in Fig. 2, and two successive days of marked variation in Fig. 3.

25 With the object of tracing the relation between relative humidity, skein regain, and temperature, Fig. 4 was plotted. As might have been expected, however, nothing definite was apparent beyond the general fact that there seemed to be such a relation.

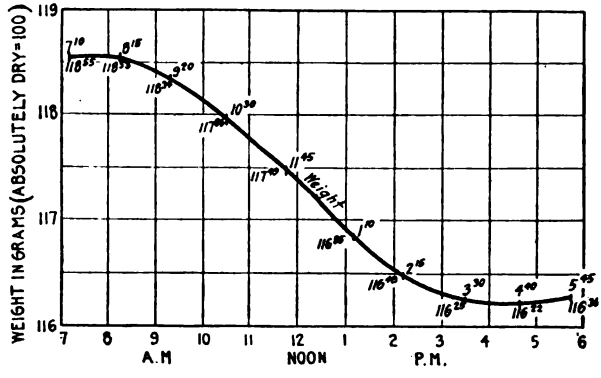

FIG. 1 AVERAGE DAILY WEIGHTS OF WORSTED SKEIN THROUGHOUT YEAR

26 The observations recorded in Table 1 gave for outdoor conditions a general average for the year of 17.45 per cent, or something less than the standard allowed abroad; and without attempting at the time to go further into the law of change, it was felt that at least it was demonstrated that a standard of 15 per cent regain for worsted, as had already been assumed, was conservative for this country.

27 Since the promulgation of this standard by the Arlington Mills in their regular business dealings in tops, all other top makers of this country have, it is understood, adopted the same standard, and it may be said to be universally accepted by the trade so far as tops are concerned. Its general acceptance on worsted yarn is perhaps only a matter of time.

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RELATION BETWEEN HUMIDITY, TEMPERATURE AND REGAIN

28 The determination of the exact relation between the three factors, humidity, temperature and regain, was a problem which the author had under investigation for some time prior to 1905. That the absorption of moisture by worsted yarn was in some man-

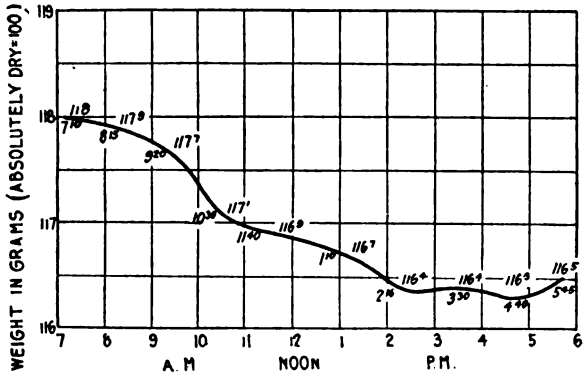

FIG. 2 VARIATION IN WEIGHT OF WORSTED SKEIN, TYPICAL DAY

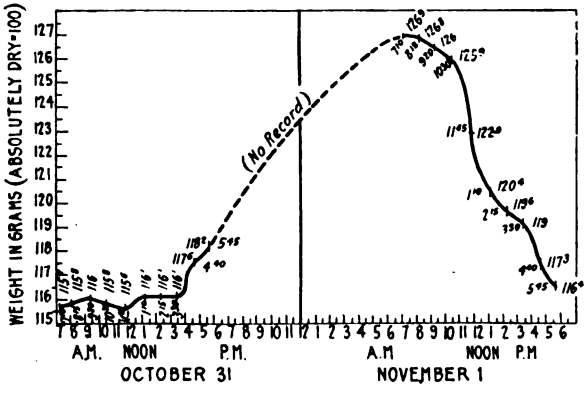

FIG. 3 WEIGHT OF WORSTED SKEIN, TWO SUCCESSIVE DAYS

ner dependent upon relative humidity and temperature was abundantly shown by the year of exterior observations recorded, and also by many interior records made subsequently. It seemed possibly true that the atmospheric pressure affected the result, but its effect was so far overshadowed by the element of temperature that, for practical mill purposes, it was evident that the height of the barom-

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eter could be neglected. In fact, all observations for either relative humidity or skein regain were made on the assumption of 30-in. barometric pressure.

29 The first efforts towards the solution of the problem of finding the relation were directed to obtaining in a closed room, for as long a period as possible, a uniform state of moisture and temperature. The difficulty of maintaining both these factors uniform for a sufficient length of time to determine more than a very limited range of facts was found to be extremely great, if not impossible,

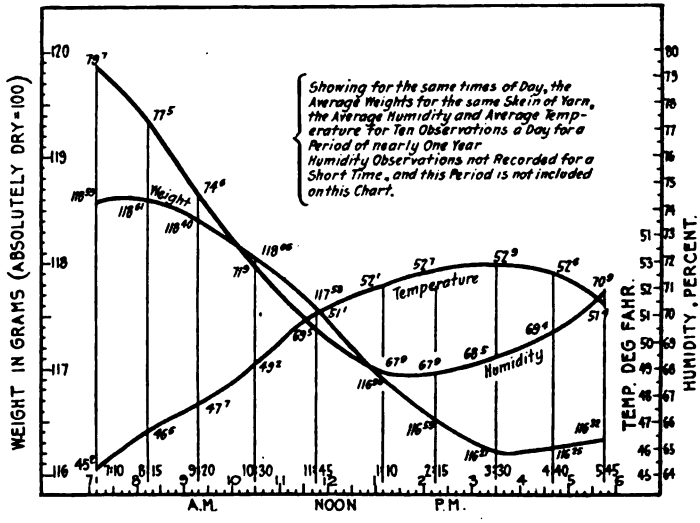

FIG. 4 AVERAGE WEIGHTS, HUMIDITY AND TEMPERATURE OF WORSTED SKEIN

with apparatus then available. So far as these facts were determined, they indicated that the same skein of worsted yarn can always be relied upon to reach the same weight under like conditions, if given sufficient time.

30 For the purpose of eliminating the effect of hard twist in retarding the absorption of moisture and the effect of oil upon the net result,[1] a quantity of 2/24 soft twist, French spun, fine Australian

[1] Experiments made under the writer's directions proved that olive oil has no appreciable effect in preventing, though it may retard somewhat, the absorption of moisture, but the amount absorbed was strictly in proportion to the dry weight of the wool, and not to the weight of the wool and oil together, though for most purposes the percentage of oil, being small, need not be considered.

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yarn was prepared and extracted with ether, dried, and extracted again with warm water to which a few drops of ammonia had been added. After allowing it to hang up for some time to come to its natural state, this yarn was made up into groups of skeins of equal lengths and approximately equal weights. The final weight and moisture state of the groups was carefully determined after they had been hung up together again for about two days, by drying out individual skeins of the different groups in the ordinary ventilated Bradford oven at a temperature of from 220 to 230 deg. fahr. until they ceased to lose weight, and also by leaving small two-gram skeins in weighing bottles under a desiccator containing strong sulphuric acid.

31 These two methods were used to check each other from time to time during the experiments, to establish the true weight of the skeins being used as moisture indicators.

32 Attention has already been called to what has been termed the "lagging effect," due to the time required by a skein of yarn to take up or part with moisture. The effect of this is to show for a given humidity and given temperature a higher result when the skein regain condition has been a falling one, and a lower result when that condition has been a rising one. In undertaking, therefore, a careful series of experiments, it was deemed necessary to make the skeins to be examined of such a size that they could be accurately weighed on a delicate balance, and not be so large that the amount of moisture which might be absorbed or parted with by a given skein would require a great many cubic feet of air to supply or displace it.

33 To insure rapid contact of moist or dry air with the skeins being tested, a small electric fan was used. The moisture state of this air was carefully determined at the moment the sample skeins were inclosed in their weighing bottles, generally by the sling hygrometer, but when circumstances did not permit of this, resort was had to a Daniels dewpoint hygrometer.

34 Upon comparing the results obtained from two skeins hung together, one of which had been previously exposed to a damp atmosphere and the other to a comparatively dry atmosphere, it was soon found that while it might require hours or even days to bring the skeins exactly together again, the mean between the two at any time after 15 or 20 min. was practically the same in repeated experiments for the same temperature and relative humidity, and presumptively equal to what a third skein would have shown which had been a long time exposed to identical conditions. It was

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therefore assumed that this means could be relied upon to quickly determine the true regain relationship for any not too rapidly changing conditions. It was thus possible to make use of the very lag effect, which had previously rendered individual observations seemingly incompatible, to establish comparatively accurate and true results. Figs. 5 and 6 are intended to illustrate this lagging-behind and coming-together effect and the method of obtaining quick results.

35 In order to compare the results obtained by this method, a special form of charting[1] was devised, shown in Fig. 7 for worsted

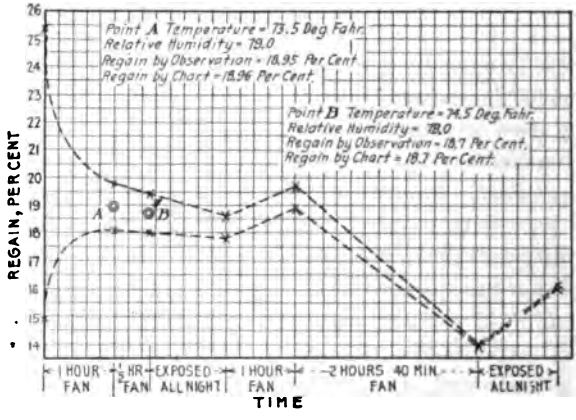

FIG. 5 LAGGING EFFECT IN SKEIN TAKING UP OR PARTING WITH MOISTURE

and Fig. 8 for cotton, on a scale greatly reduced from the original, where the ordinates represent regain and the abscissæ moisture per cubic foot of space for the temperatures and relative humidities found and shown in the figures. It will be observed that the lines joining points of the same relative humidity (for example, the 50 per cent line) cross the isothermal lines in a generally oblique direction, curved slightly convex on the downward side; that is to say, for a given relative humidity the regain is less at the higher temperature, but not less in a constant ratio.

36 By the aid of this charting principle a sufficient number of points were located to trace the isothermal and the relative-humidity

[1] For this form of charting the author is indebted to Mr. Richard P. Iddings, chemist at the Arlington Mills, who not only made the observations required in its construction but conducted a large part of those utilized in succeeding papers.

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lines shown, and from these charted results it was found possible to tabulate[1] by interpolation the percentage regain on worsted with a fair degree of accuracy for each percentage of relative humidity from 15 per cent up to near saturation, and for isothermals 5 deg. of temperature apart from 35 deg. fahr. to 100 deg. fahr.

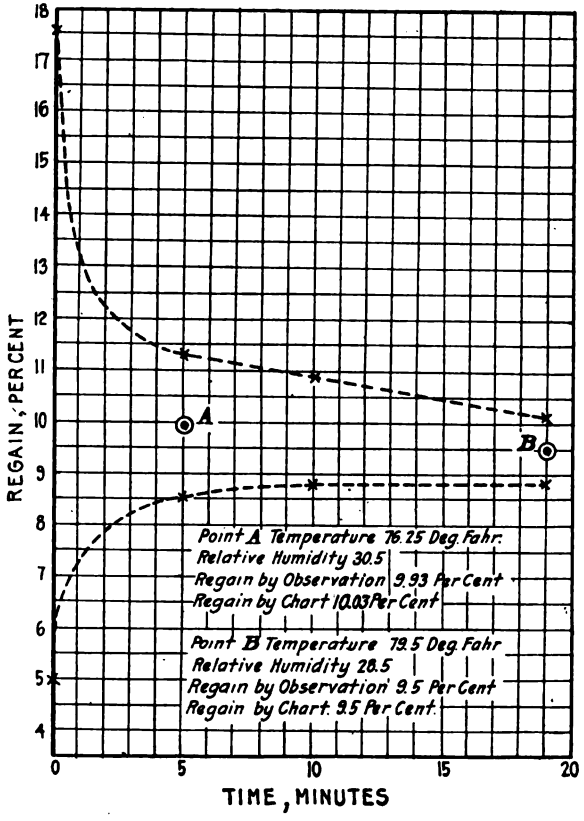

FIG. 6 LAGGING EFFECT IN SKEIN TAKING UP OR PARTING WITH MOISTURE

37 The data for securing the cotton chart were not by any means so complete as those used for the worsted chart, and therefore the same degree of accuracy was not expected for it.

[1] To avoid confusion these tables are not printed here, since those obtained six years later by a more rigid system of investigation are undoubtedly more accurate, though at ordinary temperatures and humidity the differences between the two tables are small.

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38 It will be seen from Figs. 7 and 8 that the regains for cotton are approximately one-half those for worsted under like conditions, but the relative-humidity lines are more nearly straight and therefore bear a more nearly constant ratio to the regains.

39 Another method of comparing results is shown in Fig. 9, in which curves of saturation (100 per cent humidity), 60 per cent relative humidity, 15 per cent regain in worsted, and (to avoid confusion) a number of points only on the curve of 7½ per cent regain in

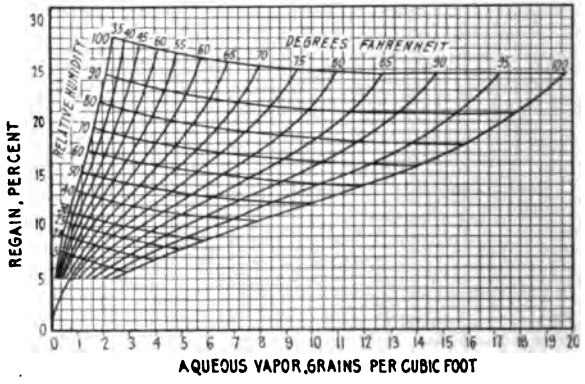

FIG. 7 ISOTHERMAL AND RELATIVE-HUMIDITY LINES FOR WORSTED

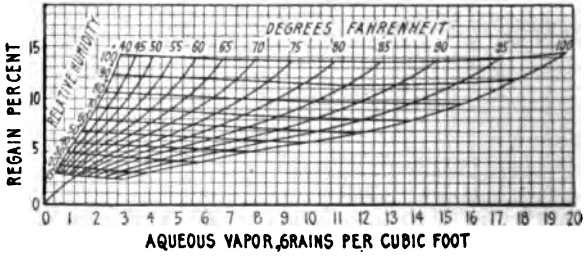

FIG. 8 ISOTHERMAL AND RELATIVE-HUMIDITY LINES FOR COTTON

cotton, are represented. An additional regain curve for 20 per cent on worsted is also shown.

40 It will be noticed that at ordinary mill temperatures the 7½ per cent curve for the cotton here used closely coincides with the 15 per cent worsted curve, and within the limits of observation their deviation is not great at either high or low temperatures. In the absence of other considerations, this fact might be taken there-

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fore as reason sufficient for establishing a 7½ per cent regain for cotton for this country, if it be conceded that 15 per cent is the proper standard for worsted.

41 It is interesting to note also that the 60 per cent humidity curve, Fig. 9, crosses the combined regain curve just named at about 77 deg. fahr., a room condition which, according to Sconfietti,[1] is

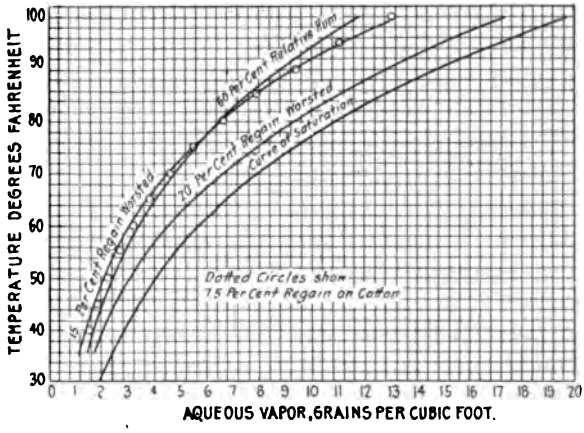

FIG. 9 REGAIN OF COTTON AND WORSTED

compatible with both good work and comfort in a cotton-spinning room.

42 Sconfietti gives his own experience, as corroborating that of other men, that the most favorable temperature for manufacturing cotton (and textile fibers in general?) is between 68 and 77 deg. fahr., while the relative humidity for cotton should be:

In carding, between 50 and 55 per cent
In spinning, between 55 and 60 per cent
In weaving, between 65 and 70 per cent

43 These figures would indicate a regain condition for cotton, by the 1911 tables, as follows:

In carding, from about 6.5 per cent to 7.2 per cent
In spinning, from about 7.2 per cent to 8.0 per cent
In weaving, from about 8.6 per cent to 9.5 per cent

[1] An interesting and instructive paper, The Humidification and Cooling of Textile Mills, by Leopoldo Sconfietti, reprinted from the *Textile Manufacturer*, 1903.

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or, in other words, for cotton the stock should be *gaining* at each step of manufacture.

44 Whether this be true or not for cotton, it is not true for worsted so far as the Bradford system of spinning is concerned. For the Bradford system of worsted spinning, even though the stock contains oil, there seems to be no doubt that it must be losing moisture during the process of spinning to make a good spin; hence the necessity, if the top contains only 15 per cent regain, for keeping the moisture condition well up during the processes of drawing and roving or else for long aging in a cool, damp cellar before going to the spinning frame. The latter plan used to be thought an absolute necessity, but modern successes in humidification have very largely obviated it.

45 The author, in his paper of 1905,[1] called attention to a paper by J. H. Lester[2] citing in turn a paper by Schloesing containing tables of the hygroscopic property of several fibers, and gave a diagram showing the relation of cotton, silk and wool for three temperatures, — 10, 24 and 35 deg. cent., by curves whose ordinates are relative-humidity percentages and abscissæ regain percentages. Fig. 10 shows a comparison of his curves for cotton and worsted at 24 deg. cent. (75 deg. fahr.) with those obtained from the author's data by the same method of charting. This publication is the first which the author had seen dealing in a scientific way with this subject, and he is indebted to both Lester and Schloesing for the stimulation to further research effort resulting in his paper, The Laws of Regain in Cotton and Worsted, published in Transactions of the National Association of Cotton Manufacturers, Vol. 90, 1911.

46 Schloesing's paper referred to by Lester[3] was translated in the *Textile World Record*, November 1908, by Samuel S. Dale. It appears that there was also an abstract of this paper in the Journal of the Society of Chemical Industry, Vol. 13, 1895.

[1] For purposes of a broader record, the author has here before abstracted quite freely from his 1905 paper, Some Comparative Data on Moisture in Cotton and Worsted, and he has taken much that immediately follows, verbatim, or with but slight changes, from his paper of 1911, on The Laws of Regain in Cotton and Worsted.

[2] Moisture in Cotton and Yarn, J. H. Lester, British Assoc. of Managers of Textile Works, December 10, 1904.

[3] Research on the Hygroscopic Properties of Various Textile Materials, M. T. Schloesing, Jr., Bul. Soc. d'Encouragement pour L'Industrie Nationale, 1893.

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47 One of Schloesing's methods involved the use of pure sulphuric acid of known strengths in obtaining known and comparatively constant states of relative humidity in a closed vessel or chamber.

48 Both of his methods, though checking up well with each other, involved the question of control and length of time required to arrive at results — a time so great that to apply them over a wide range of temperatures to make a complete comparison with the writer's figures seemed out of the question. The sulphuric-acid method was the simplest but, though making use of conditions of

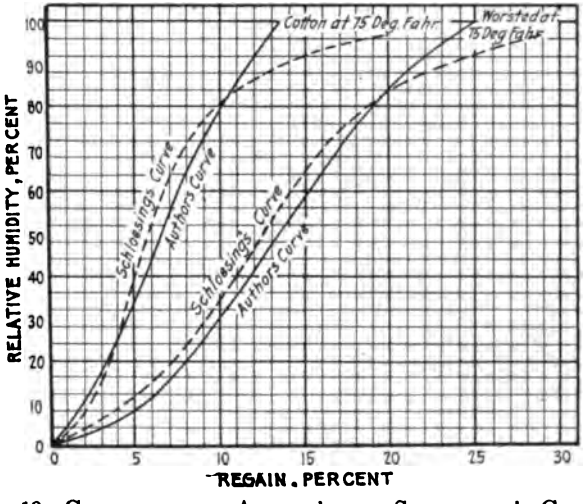

FIG. 10 COMPARISON OF AUTHOR'S AND SCHLOESING'S CURVES

known humidity in obtaining the facts (not the law) of regain, neglected the phenomenon of lag — one of the time elements in the problem.

49 It is true that Mason and Richards recognized the lag element[1] and in their experiments on absorbent cotton made use of it after a certain manner, but the experiments as reported did not seem to extend far enough to generalize as to the law of regain. The basis for a general law for such regain was, however, announced by the writer in his 1905 paper, and its specific application made for worsted at a single temperature (70 deg. fahr.) with a fair degree of consistency with the actual observations charted and tabulated as described.

[1] Hygroscopic Action of Cotton, O. Mason and E. S. Richards, Proc. Royal Soc., 1906, 78A, pp. 412–429.

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ELIMINATING THE LAGGING EFFECT

50 · These observations, however, were not accurate enough to correlate results with mathematical precision for different temperatures, particularly at the higher humidities. To accomplish this, it was necessary to obtain the elimination of the lagging effect by direct observations under conditions of constant temperature and constant humidity indefinitely maintained, or so closely known that the constant condition required could be calculated. In attempting

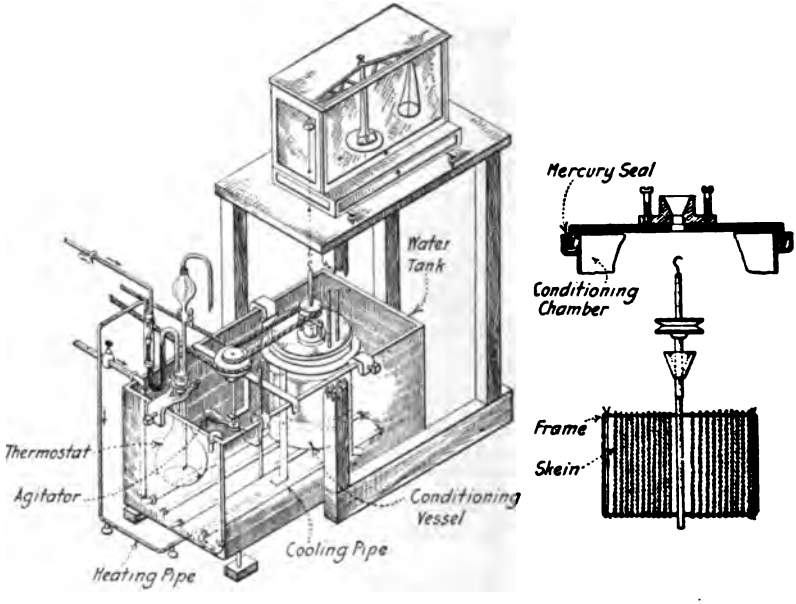

FIG. 11 APPARATUS FOR DETERMINING REGAIN

this, use was made of Schloesing's sulphuric-acid method in an apparatus developed after much experimenting, shown in Fig. 11, so that observations could be repeated over and over again under conditions calculably alike upon the same and upon different pairs of skeins to obtain a satisfactory average for a given kind of material at as many points of temperature and humidity as desired.

51 The principle of operation of the apparatus is: A pair of skeins, one moister and the other drier than the proposed humidity would give, are hung on the two ends of a specially designed metal frame within an enclosed metallic vessel, the cover of which is sealed

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by mercury. Excepting the top, this vessel is entirely surrounded by water, the temperature of which can be kept constant by a thermostat. In the bottom of this chamber, paraffined for protection, varying known strengths of sulphuric acid are placed and the framework revolved in the air above by a small motor, which also turns an agitator in the outside water. Thermometers pass through the lid of the sealed chamber, one terminating in the air and the other in the liquid below, so that the exact temperature of each is known and, therefore, the exact equilibrium conditions calculable.[1] The bearing for the shaft is a copper tube held in a conical plug, making a practically airtight joint. When it is desired to weigh the combination the driving band is disengaged and the hook from the scale above inserted in the hook of the shaft of the framework, just lifting it from its conical bearing so that the weight can be taken accurately.

52 It will be noted that: *The original dry weights of the skeins having by calculation from blank tests on other skeins been made equal, one-half of the sum of the weights found always represents the average present condition of the two skeins.*

53 If it should happen that the heavier skein was relatively moister than the lighter skein was relatively dry, compared with the humidity condition, the sum of the weights would in time diminish. If, on the other hand, the dry skein was drier in proportion than the wet skein was wet, then the sum of the weights would increase by exposure in this vessel to the constant conditions of humidity. The revolution of the frame holding the skeins tends to keep all conditions uniform during an experiment.

54 It was soon found that in about an hour's time an equilibrium was established between the two skeins so that there was neither gain nor loss thereafter, while the temperature remained the same.

55 *It was, however, found on repeating the same experiment on the same pair of skeins, in the same order, that is, the same skein always remaining the drier, that the successive observations gave continually lower*

[1] For state of equilibrium between H_2SO_4 and superincumbent atmosphere at all ordinary temperatures, Mason gives the following table in Transactions J.S.C.I., Feb. 15, 1907, vol. 26, no. 3, p. 89:

Per cent H_2SO_4	73.8	67.0	59.0	52.6	47.2	43.1	40.5	38.8	32.3	26.8	23.2	20.3	18.1	10.3	6.2
Per cent H	5	10	19.8	29.4	40.8	50.0	55.6	59.8	71.0	79.4	84.4	87.4	89.4	95.2	97.2

By constructing a curve with these two values as coördinates, any intermediate relationship can be obtained graphically.

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results for the average regain; but if the skeins for a repeated experiment were alternated in the exposing condition, that is, if the one which had been drier in the first instance was made the damper in the second, then the results represented a very nearly constant condition of regain, not only for the same pair of skeins but for duplicate pairs, and in the final accepted results a series of tests on duplicate samples alternating for the moist and dry state in each were averaged for each point of regain determined.

56 By suitable humidities and temperatures thus predetermined and accurately controlled, points of regain in sufficient number were found not only to confirm the basis for the general law previously propounded in 1905, but to extend its application so as to cover for both worsted and cotton the relationship of humidity and regain at all temperatures within the limits of the apparatus as arranged, giving reliable results not previously found possible.

57 The largest number of experiments was made on carefully cleansed skeins of soft twisted 2/24 worsted, French spun without oil, from Australian merino wool, and on skeins of two-ply, seven-hank roving, soft-twisted from combed Sea Island cotton in its natural state. Check tests were also made on coarse cross-bred worsted yarn and bleached Sea Island cotton (nearly pure cellulose), but only enough to show that while the results were not identical, no great variation was to be expected between different kinds of wools and between yarns made from the same cotton in different conditions. Having obtained these accurate comparative points, the mathematical considerations as first announced in 1905 and their further application to the more complete conception of the laws of regain as developed in 1911 are here restated with some extension and some abridgment of comparisons and corrections to make the reasoning more clear and to avoid unnecessary repetition.

MATHEMATICAL CONCEPTION OF THE LAWS OF REGAIN

58 A formula[1] for obtaining the weight of a cubic foot of saturated aqueous vapor at different temperatures is of the form

$$W = 11.7449 \frac{E}{1 + 0.002037\ (t - 32)} \quad \ldots\ldots\ldots\ldots [1]$$

where W = weight required; E = maximum elastic force of aqueous vapor at the temperature t deg. fahr.; coefficient 11.7449 =

[1] Pamphlet No. 235, U. S. Weather Bureau. Contains elaborate psychrometric tables by Prof. C. F. Marvin.

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$(0.0807 \times 7000 \times 0.6221) \div 29.921$. In the latter, 0.0807×7000 = weight in grains of 1 cu. ft. of dry air under the standard barometric pressure of 29.921 in. of mercury, and 0.6221 = calculated specific gravity of aqueous vapor under the same conditions. Coefficient 0.002037 is the measure of the expansion of a true gas for each degree of temperature (fahr. scale) for unit volume when the absolute zero is taken as −459 deg. fahr., and for these values the equation may be more simply written

$$W = 5766.7 \frac{E}{T} \quad [2]$$

in which T is the absolute temperature and E is the corresponding maximum elastic force of aqueous vapor.

59 The saturation curve in Fig. 9 may be said to be represented by the above equation as a particular case of the more general one representing any curve of relative humidity:

$$HW = H \times 5766.7 \frac{E}{T} \quad [3]$$

in which H = relative humidity expressed as a fraction of unity.

60 This equation and Fig. 9 may be said to be the foundation of the discussion of this subject, but in the interest of readings to compare more closely with other data the absolute zero was later assumed to be −459.4 deg. and the coefficient 0.002037 in Eq. [1] replaced by its more exact value 1/491.4, so that the fundamental equation reads

$$HW = H \times 5771.44 \frac{E}{T} \quad [4]$$

61 Referring again to Fig. 9, it is clear that there is a varying relationship for each point of a curve of regain to the coördinating values HW and t (or T), and this may be expressed by an equation in the form

$$HW = K'RT^2E \quad \text{or} \quad K' = \frac{HW}{RT^2E} \quad [5]$$

in which K' is a variable coefficient depending upon R and T, and in consequence upon H, for different curves of regain. The value of K' for any particular regain at any particular temperature can be found by calculation directly from tables of saturation and elastic tensions and tables of observations of regain and humidity, such as those prepared from the charts in the author's 1905 paper. For instance, for 50 deg. fahr. temperature and 20 per cent regain, the chart tables show H = 76 per cent and Professor Marvin's tables

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give $E = 0.360$ and $W = 4.076$, $K' = (0.76 \times 4.076) \div 20 \times (509)^2 \times 0.360 = 0.00000166$. As K' is a minute fraction, it is more convenient to substitute $10^{-8} K$, in which K is a whole number, or for K' above, $K = 166$.

62 Advantage was taken of this relation to tabulate values of K for each per cent of regain from 5 to 24, and for the isothermals shown in Fig. 7 from 35 to 100 deg. Plotting corresponding curves showed a general parallelism (see Fig. 12) indicating a conic-section type. Selecting five points for the 70-deg. curve, its equation was produced, and by values calculated therefrom the curve of K for

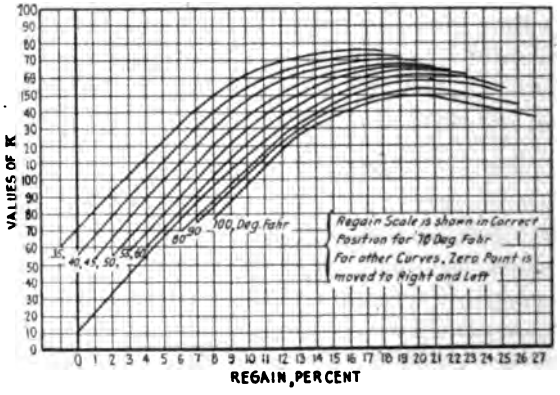

FIG. 12 REGAIN SCALES FOR WORSTED

70 deg. is plotted in Fig. 12. The isothermal for 70 deg. is also plotted in Fig. 7, using the original empirical Equation [5] in the form $R = (HW) \div (10^{-8} KT^2E)$. The close approximation of the calculated results to the actual observations used is apparent. However, in reviewing this work of 1905 to conform with more accurate observations of 1911 it seemed best not only to use the revised value for $W = 5771.44\, E/T$, but since it had been shown that $HW = 10^{-8} KRT^2E$, to write

$$10^{-8} KRT^2E = H \times 5771.44 \frac{E}{T} \quad \ldots\ldots\ldots\ldots\ldots [6]$$

or

$$KRT^3 = H \times 5771.44 \times 10^8 \quad \ldots\ldots\ldots\ldots\ldots [7]$$

which shows that the product KRT^3 is a constant quantity for all temperatures at the same humidity. From this also we can write

$$KR = H \times 5771.44 \times 10^8 \div T^3 \quad \ldots\ldots\ldots\ldots\ldots [8]$$

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which is a definite quantity for any given temperature for each per cent of humidity. Thus, at 70 deg. fahr. for H = unity or saturation,

$$KR = \frac{5771.44}{(529.4)^3} \times 10^6 = 3890$$

It is also evident that KR and H each become zero at the same time, and in an equation for determining the relative values of K and R there are, therefore, two points whose conditions are known without observation, namely:

63 *First* For $R = 0$, $K = 0$, or the curve represented by the equation passes through the origin of coördinates.

64 *Second* The point of saturation is conditioned so that $KR = 3890$, and it is only necessary to know accurately three other points to determine the equation in full, if it be of hyperbolic form, which observation indicated.

65 The three other points which we now use for this purpose were obtained in the manner already described, and for worsted are represented by the coördinates:

$$B = \overset{R}{7.03}, \overset{K}{109.6}; \quad C = \overset{R}{14.13}, \overset{K}{153.1}; \quad D = \overset{R}{23.10}, \overset{K}{149}$$

the tabulated observations for which are given in the Appendix for relative humidities of 19.8, 55.6 and 88.4 per cent, respectively.

66 The condition $KR = 3890$ implies that the curve in question must be tangential to a curve whose equation is

$$xy = 3890$$

and the precise location of this point of tangency was obtained by the cut-and-try method of assuming a point, which experiment with the apparatus referred to showed must be very close to 100 per cent humidity (though it was impossible to be certain of its correct observation), and, finding that the curve so obtained crossed the curve of $xy = 3890$, the true tangential point was assumed to be (and must have been very closely) halfway between the two points of crossing. The coördinates of this point being supplied, the equation can be rewritten with a high degree of precision.

67 Without, however, going through this preliminary work, it is sufficient to say that the five points used were the three observed points already given and the points:

$$A = \overset{R}{0}, \overset{K}{0}; \quad E = \overset{R}{32.5}, \overset{K}{119.7}$$

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68 The final equation for the values of K for worsted at 70 deg. is expressed as follows:

$$y^2 - 22.3\,xy. - 138\,x^2 - 420.7\,y + 8263\,x = 0 \ldots\ldots\ldots [9]$$

which evidently gives the condition $B^2 - 4\,AC > 0$, and therefore the curve is a hyperbola.

69 From this equation the schedule of values for R and corresponding values of K, KR, and H, for the 70-deg. curve on worsted, as given in the Appendix, Table 6, were obtained.

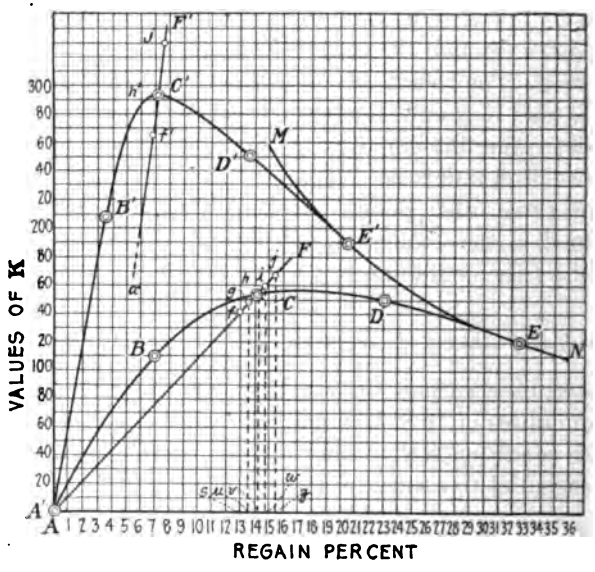

FIG. 13 VALUES OF K, SATURATION CURVE $xy = 3890$, ETC.

70 Similar conditions were made use of for obtaining the curve for values of R and K for Sea Island cotton, the five points used being

$$A = \overset{R}{0},\ \overset{K}{0};\quad B = \overset{R}{3.68},\ \overset{K}{207.6};\quad C = \overset{R}{7.33},\ \overset{K}{293};$$

$$D = \overset{R}{13.73},\ \overset{K}{250.6};\quad E = \overset{R}{20.6},\ \overset{K}{188.8}$$

and its equation at 70 deg. is as follows:

$$y^2 - 51.87\,xy - 578.7\,x^2 - 397.88\,y + 2362.5\,x = 0. \ldots.[10]$$

71 This also gives the condition $B^2 - 4\,A\,C > 0$, and therefore represents a hyperbola.

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72 From Eq. [10] the schedule of values for R, K, KR and H for the cotton curve, as given in the Appendix, Table 5, was obtained. Both of these curves and the curve of saturation, $xy = 3890$, for 70 deg. fahr., are given in Fig. 13. It remains now to consider how to obtain the relationship between K and R at other temperatures than 70 deg., which could not be determined from the observations or the methods used in the 1905 paper.

DETERMINATION OF RELATION BETWEEN K AND R AT OTHER TEMPERATURES

73 In Table 3 in the Appendix will be found detailed observations for the worsted regain at 55.6 per cent humidity at four different temperatures in addition to those made at this humidity for the curve of 70 deg., given in Table 2. The average for each of these, together with that for the 70-deg. curve, with corresponding values for KR and K (the fifth column to be explained later) are:

TABLE FOR WORSTED AT 55.6 PER CENT HUMIDITY

t	Observed R	KR	K	$R = R_1 T_1^{\frac{1}{2}} / T^{\frac{1}{2}}$
40	15.39	2576	167.4	15.42
55	14.77	2357	159.7	14.75
70	14.13	2163	153.1	14.13 as R_1
85	13.52	1989	147.1	13.55
100	13.00	1833	140.6	13.01

74 Plotting these points of regain by their coördinates K and R in Fig. 13, and drawing a straight line through the origin and through the point corresponding to 70 deg., all the above points are found to be almost exactly on this line. Assuming them to be on the line, their respective coördinates would be the sides of similar right-angled triangles; and the K of one is to the K of another as the R of the first is to the R of the second, that is, $R : R_1 :: K : K_1$, or

$$K = \frac{R}{R_1} K_1 \ldots\ldots\ldots\ldots\ldots\ldots [11]$$

But since it has already been shown that for the same humidity KRT^3 is a constant quantity for all temperatures, then $KRT^3 = K_1 R_1 T_1^3$. Substituting in this the value of K in terms of R, R_1 and K_1 as above, we can write:

$$R^2 T^2 = R_1^2 T_1^3$$

or

$$R^2 : R_1^2 :: T_1^3 : T^3$$

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That is, for worsted, *for the same humidity, the squares of the regains at the different temperatures are to each other inversely as the cubes of the corresponding absolute temperatures*, or we may write

$$R = R_1 \frac{T_1^{\frac{1}{3}}}{T^{\frac{1}{3}}} = R_2 \frac{T_1^{\frac{1}{3}}}{T^{\frac{1}{3}}}, \text{ etc. } \ldots\ldots\ldots\ldots\ldots [12]$$

Applying this formula to the regain at 70 deg., as observed, the results check out as shown in the fifth column above referred to.

75 This is as close as the limits of accuracy for the observations can be expected to show. Regains at other humidities and different temperatures were checked up in a similar way, so that the law can be said to be well established within the range of temperatures named. It is by the application of this formula that Table 7, given in the Appendix, of regains for worsted at other temperatures than 70 deg. fahr., for each per cent of humidity from 1 to 100, was calculated.

76 It is quite probable that this law holds good for temperatures higher than 100 deg., but the apparatus used was not adapted to temperatures much higher than this, and it is therefore not yet established at what temperature the change in hygroscopic capacity on both worsted and cotton, which is known to exist at 220 deg. fahr., begins.[1]

77 Upon examination of the regains found on cotton at different temperatures for the same relative humidity, it is at once apparent that the law of relationship is not the same as for worsted. The average of a number of observations are compared in the tables below, supplying in both instances the observed values at the same humidities from the 70-deg. curve. In the first table are given the values of KR and K. The fifth column in the first table and the third column in the second are prepared on the assumption that the law of relation for regain at different temperatures on cotton is $R : R_1 : : T_1 : T$, using R_1 as observed for 70 deg.

[1] An attempt has been made by the writer to determine at what temperature this change in hygroscopic capacity begins. The results of these experiments are not in a form that can be presented here, but it is sufficient to say that it seems highly probable that this change in hygroscopic capacity, on clean wool at least, is only temporary and not permanent, even up to 220 deg. or 230 deg., unless some portion of the wool or cotton has been scorched, but this scorching may imply either a considerably higher temperature than 220 deg. or an unnecessary prolongation of the heated condition for such portion. The phenomenon noted in par. 55 may have an important bearing upon this question.

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COMPARATIVE TABLE FOR SEA ISLAND COTTON OF 55.21 PER CENT HUMIDITY

t	Observed R	KR	K	$R = R_1T_1/T$
40	7.76	2557	329.5	7.77
70	7.33	2148	293.0	7.33 as R_1
100	6.89	1820	264.1	6.94

COMPARISON AT 19.64 PER CENT HUMIDITY

t	Observed R	$R = R_1T_1/T$
70	3.68	3.68 as R_1
100	3.47	3.48

78 The results as calculated are certainly remarkably close to those obtained by observation. Similar comparisons were made at other humidities and other temperatures, so that it would seem without other consideration that the law had been very closely established within the range of temperatures observable in the apparatus used.

79 Plotting the points of regain on Fig. 13 by their coördinates R and K found in the above table, it will be noticed that these points are not in a straight line. Applying the principle to other points the curve is plotted to a limited extent thereon. Since, however, the relationship between R and T appeared so simple, it was not necessary to carry the investigation in this direction further. Its statement for cotton (specifically Sea Island cotton in its natural state) is: *For the same humidity the first powers of the regains at different temperatures are to each other inversely as the first powers of the corresponding absolute temperatures, or*

$$R = R_1 \frac{T_1}{T} \qquad [13]$$

80 It is by the application of this formula that Table 8 of regains for cotton at other temperatures than 70 deg. for each per cent of humidity was calculated.

81 Considering the fact that the original methods used were primitive in character, it is interesting to see how closely the tables prepared in 1905, both for worsted and cotton, for ordinary temperatures and humidities, agree with those now more accurately

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determined. The difference between the tables for cotton for all temperatures up to 50 per cent humidity is not greater than one-half of one per cent. In the case of worsted the margin of difference is a little larger, but not very materially. For the higher humidities the 1905 tables for both cotton and worsted are undoubtedly too low, and the results of Schloesing's experiments at such temperatures as he gives are more nearly correct.

82 A comparison between Schloesing's curves on cotton and worsted at 24 deg. with the author's new curves at 75 deg., using relative humidity for one coördinate and regain for the other, as

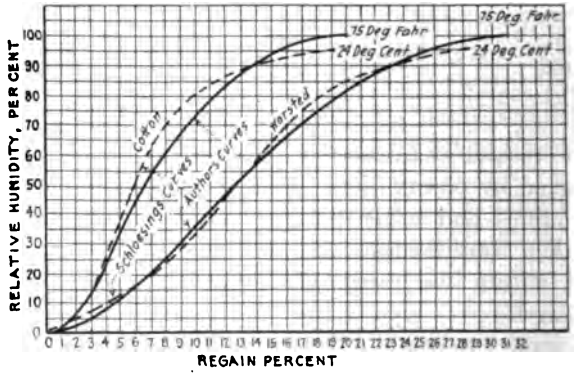

FIG. 14 COMPARISON OF AUTHOR'S AND SCHLOESING'S CURVES

was used in his method of charting, shows the present relationship of these curves as much nearer than exhibited in the first paper. Under the present understanding of the subject, however, the author believes that Schloesing's figures are too high above 90 per cent humidity, particularly so on cotton. (See Fig. 14.)

SUMMARY

83 To summarize these laws of regain in cotton and worsted, we can say:

84 *First* The general law for cotton and worsted, and probably for any other textile fiber, may be expressed by the formula

$$KRT^3 = H \times 5771.44 \times 10^6 \ldots\ldots\ldots\ldots\ldots [7]$$

in which H represents any given relative humidity expressed decimally; R the regain at any absolute temperature T; K is a variable coefficient depending upon H, R and T in such a way that for $H = 1$, or saturation, the product KRT^3 is a constant quantity represented

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by the number 5771.44×10^6. In this, 5771.44 is the weight in grains of a cubic foot of aqueous vapor at any temperature multiplied by the corresponding absolute temperature in degrees fahrenheit, divided by the maximum elastic force of aqueous vapor at that temperature expressed in inches of mercury. In this expression, therefore, we are independent of tables for saturated aqueous vapor, either for unit of weight or elastic force.

85 *Second* For any given temperature the relation of values of R to the variable K, for both worsted and cotton, is expressed by a hyperbolic equation, differing for each substance.

86 *Third* For any other temperatures the law for worsted is: *For the same humidity the squares of the regains at different temperatures are to each other inversely as the cubes of the corresponding absolute temperatures.*

87 *Fourth* The law for cotton is: *For the same humidity the first powers of the regains at different temperatures are to each other inversely as the first powers of the corresponding absolute temperatures.*

88 No other substances have as yet been compared in this manner by the writer, but for such substances it is quite possible that all these relations, except those of the general formula, may be decidedly different.

ANOTHER METHOD OF CHARTING AND FURTHER DEDUCTIONS EXPLAINED [1]

89 Though graphically expressing the relations and laws referred to, the charts so far shown do not lend themselves readily to accurate portrayal of the established facts at all points of their construction, nor are they adaptable for every-day use. By properly constructed charts on a unit-system basis it is possible to avoid the necessity for using any tables in either hygrometric observations as such, or the reading of the corresponding conditions of equilibrium therewith for the several textile materials.

90 Figs. 15 to 19 were devised for this purpose, so far as commercial and mill uses require, for wool and cotton. On each of them the vertical lines represent (as labeled) 5-deg. intervals of temperature and the horizontal lines 5 per cent intervals in relative humidity: For closer reading, each degree and each per cent are marked off respectively at the top and bottom and on both sides of the charts.

[1] Bul. National Association of Wool Manufacturers, vol. 45 (1915), p. 93. Also Trans. National Association of Cotton Manufacturers, vol. 98 (1915), p. 254.

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91 *Barometric Corrections.* Fig. 15 is needed in ordinary mill use only in a negative sense. It shows the effect of the height of the barometer, by unit variations, in obtaining the correct relative humidity from readings of the sling hygrometer, and can be read as closely as necessary for practical purposes. On it and on Figs. 16 and 17 the curves running in a convex upward direction from left to right and labeled from 1 to 40 deg. downward represent the position of unit differences in the wet-and-dry bulb readings of a sling hygrometer and are plotted from relative humidities, with barometer at 30 in., very carefully calculated to the nearest one-tenth of 1 per cent.[1]

[1] The formula used in making the calculations was a simplified form of one deduced by Professor Ferrel, found in the U. S. Weather Bureau Report, No. 235, published in 1900.

The formula reads:

$$e = e' - 0.000367\,P\,(t - t')\left(1 + \frac{t' - 32}{1571}\right)$$

In this, all pressures being measured in inches,

P = height of barometer (all corrections applied)

t = temperature of dry bulb in fahrenheit degrees

t' = temperature of wet bulb in fahrenheit degrees (both as shown on sling hygrometer)

e' = the saturated or maximum vapor pressure at temperature t'

e = actual vapor pressure corresponding to observed t and t'.

Now calling $t - t' = d$, the writer's simplification of the formula becomes:

$$e = e' - d\,(0.0108 - 0.000007\,t')\,\frac{P}{30} \quad \text{(see Note below)}$$

and the relative humidity corresponding is calculated as

$$H = 100\,\frac{e}{E},$$

where E = saturated or maximum vapor pressure at temperature t.

When the temperature of the *dewpoint* is or can be determined directly by a dewpoint apparatus, the corresponding maximum vapor pressure for that temperature is the value e in the above equation, and is by *definition* independent of barometric pressure.

The Report No. 235, referred to, contains tables of maximum vapor pressures extended to three decimals, as used by the U. S. Weather Bureau.

For a humidity chart of somewhat similar design, but less comprehensive, also based upon Professor Ferrel's formula, see an article on Pitot Tubes for Gas Measurement, by W. C. Rowse, Trans.Am.Soc.M.E., vol. 35, p. 688.

This chart did not come before the writer's notice until after the major part of his charts were prepared and photographed, and they are in no way dependent upon it.

Note: — The only portion of this formula which is affected by the height of the barometer is $d\,(0.0108 - 0.000007\,t')$, and it is from this portion that the data for the barometric-correction curves on Fig. 15 have been calculated.

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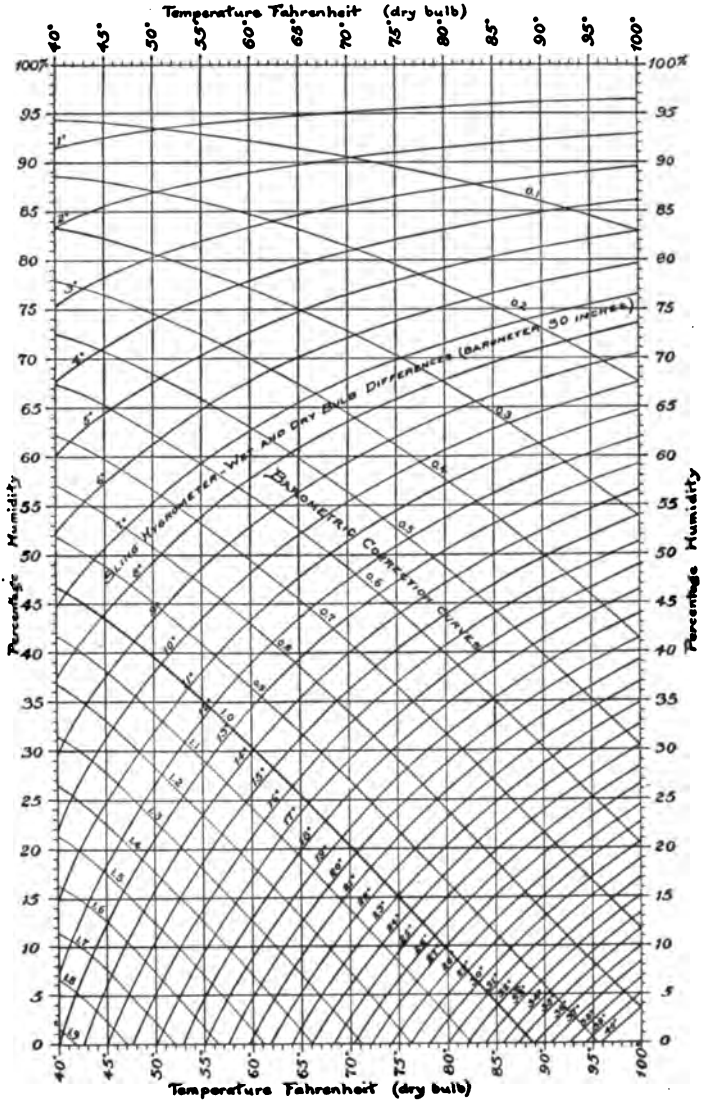

FIG. 15 BAROMETRIC-CORRECTION CHART

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92 The lines crossing these wet-and-dry-bulb difference curves and running from left to right, concave downward, are designated barometric-correction curves. They are labeled, beginning at the lower left-hand corner, 1.9, 1.8, 1.7, etc., to 1.0, and then continuing 0.9, 0.8, etc. Their significance is this: the correction in per cent to be added to or subtracted from the humidity findings by the chart curves will be one times the drop of the barometer in inches below 30, and one times the rise above 30, respectively, on every reading falling on the line labeled 1.0, and 0.9 times 0.5 times or 1.1, etc., times such readings falling on the curves so labeled.

93 For readings *falling between* these lines, a relative estimate can be interpolated by inspection, if need be.

94 *Regain Curves.* Figs. 16 and 17 are intended to be used in determining from sling-hygrometer readings both absolute and relative humidities, within the limits of temperature indicated and the corresponding regains, for a state of equilibrium therewith on wool and cotton respectively.

95 Figs. 18 and 19 show within the same limits of temperature the unit-variation regain lines for wool and cotton with respect to the absolute- and relative-humidity lines in whatever manner either may have been determined.

96 On each of these four figures the unit-regain curves are nearly straight lines for both clean wool and cotton, running in a general upward direction from left to right, and labeled from 1 to 32 per cent on the wool charts, and from 1 to 20 per cent on the cotton charts.

97 In Figs. 18 and 19, besides the unit-difference curves, there are three extra lines, two in Fig. 18 and one in Fig. 19, labeled, respectively, 15.5 per cent, 18.25 per cent and 8.5 per cent. These, with the three emphasized lines at 15, 19 and 20 per cent, represent equilibrium conditions for certain commercial standards in wool and cotton, to be more fully described and explained later.

98 All these lines are plotted from data developed either directly from the writer's original formulæ, or, where admissible, by interpolation from the tables in the Appendix.

99 *Absolute-Humidity Curves.* In each of Figs. 16 to 18 are plotted curves running from left to right in a convex direction downward, labeled respectively 1 grain, 2 grains, 3 grains, etc., up to 19 grains, which represent weights of aqueous vapor per cubic foot under the temperature and relative-humidity conditions indicated at

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their points of intersection with the temperature and humidity lines. These curves are plotted from data calculated from Professor Marvin's Table 12 in U. S. Weather Bureau Report No. 235.

ILLUSTRATIONS OF THE PRACTICAL USE OF THE CHARTS

100 Assuming a 30-in. barometer, suppose an observation by the sling hygrometer gave a dry-bulb temperature of 65 and wet-bulb of 60 deg. Note in Fig. 16 that the 5-deg. difference curve crosses the vertical 65-deg. temperature line just a little below its intersection with the horizontal 75 per cent humidity line; that the curve for 5 grains of aqueous vapor per cu. ft. crosses a little to the left of; and the 19 per cent regain for clean wool exactly at, the same 75 per cent point. The results would be properly recorded:

Temperature, deg. fahr.	65
Relative humidity, per cent	75
Absolute humidity, gr. per cu. ft.	5.1
Wool regain, per cent	19
Cotton regain, per cent	10.7 (Fig. 17)

101 It will be observed that even on the reduced scale of Fig. 16 it would be possible to read the relative humidity closer and call it 74.8 per cent and the other items correspondingly less; but it would not be worth while to do so for a single observation, because that degree of accuracy would rest upon the assumption that the difference in the wet- and dry-bulb temperatures had been taken with an observation error of less than one-tenth of a degree — an improbable supposition, except with a very careful observer using very refined instruments.[1] Mill observations are usually taken to the nearest

[1] Attention is called to a very accurate, though expensive, instrument of the wet- and dry-bulb type, using a small spring-driven suction fan to take the place of the effect of whirling in the ordinary sling type. It is called an aspirations-psychrometer (by Assmann) and is made by R. Fuess, vorm. J. G. Greiner, Jr., and Geissler, Steiglitz, nr. Berlin, Germany.

The temperature graduations are to 0.2 deg. cent., and the tables of vapor pressures accompanying are in millimeters, instead of inches of mercury.

The instrument can be used directly with these charts by simply converting the thermometer readings to the fahrenheit scale. The writer has found it capable of closer work than the ordinary sling instrument.

When translated into inches of mercury for corresponding temperatures fahrenheit, the vapor pressures given agree very closely with the tables given in U. S. Weather Bureau Report No. 235. The writer has compared them also with those given by Marks and Davis in Steam Tables and Diagrams, 1910. The

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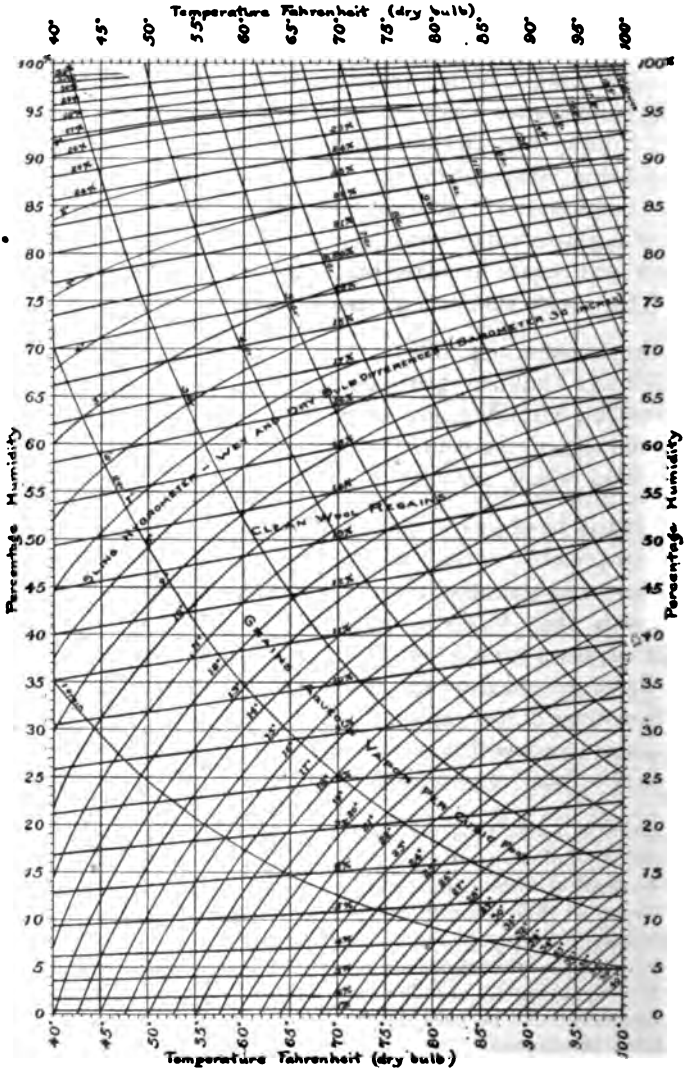

FIG. 16 ABSOLUTE, RELATIVE-HUMIDITY AND REGAIN CURVES, WOOL

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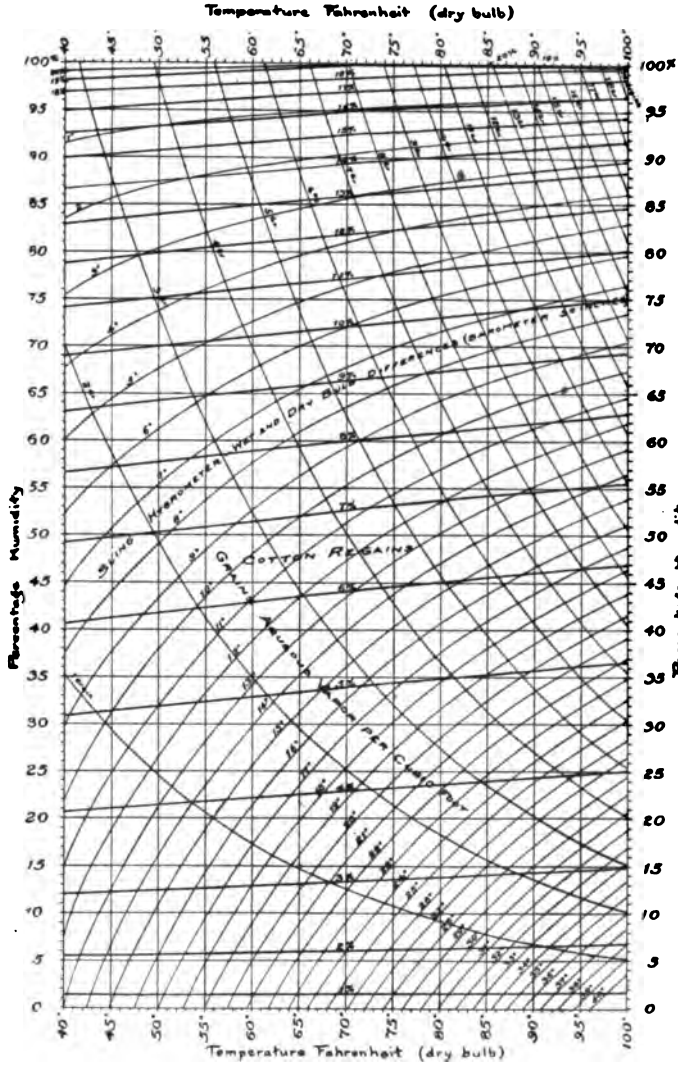

FIG. 17 ABSOLUTE, RELATIVE-HUMIDITY AND REGAIN CURVES, COTTON

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½ deg., implying a possible error of over 0.2 deg., or as much as 1 per cent in any single record of humidity, under approximately like conditions.

102 Again, under like circumstances, referring to Fig. 15, it will be seen that the observed point falls approximately on the barometric-correction curve 0.3, which means that it would require a difference of 3½ in. in the barometer, more or less than 30, to make a difference of 1 per cent in the humidity reading; or in other words, an amount no greater than the possible error of an ordinary mill observation.

103 For dry bulb 77½ deg., wet bulb 61 deg., difference 16½ deg., the point is found at:

Temperature, deg. fahr.	77½
Relative humidity, per cent	37½
Absolute humidity, gr. per cu. ft.	3.8
Clean-wool regain, per cent	10.3 (Fig. 16)
Cotton regain, per cent	5.3 (Fig. 17)
Barometric-correction factor	0.65 (Fig. 15)

104 In this case, to need a correction of as much as 1 per cent in the humidity record, involving 0.2 per cent and 0.1 per cent only in the reading for the regain conditions of wool and cotton, respectively, would require [since $1.00 \div 0.65 = 1.54$] a drop in the barometer to below 28½ in. or a rise to above 31½ in.

OTHER INTERPRETATIONS AND INFERENCES

105 As regards barometric corrections in mill practice, the humidity conditions usual either for warehouse storage or manufacturing rooms evidently lie above the barometric-correction curve labeled 1.0; and Figs. 16 and 17 show that it requires, for conditions in the neighborhood of this line, a difference of about 5 per cent in relative humidity for wool and 10 per cent for cotton to make as much as 1 per cent difference in their respective regain conditions.

differences are so small between these three tables that, for ordinary purposes, either may be regarded as giving practically correct results.

The formula given with these German tables for calculating the relative humidity differs slightly from that deduced by Professor Ferrel.

Using this German formula gives humidity readings slightly higher than Professor Ferrel's formula, with a maximum of about 2 per cent at the lower left-hand corner of the chart. Within the limits of mill temperatures, the variation higher is within the neighborhood of one-half of one per cent.

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Consequently the probable maximum effect upon humidity readings of any barometric change likely to occur in our latitude and at elevations not exceeding 1000 ft. would only be equivalent to about one-half of one per cent in the proper reading for the regain of wool and one-quarter of 1 per cent for cotton.

106 The common custom, therefore, of paying no attention to barometer readings in observations for moisture conditions in factories not situated at high elevations is quite justifiable from a practical standpoint. Moreover, it may be noted here that contrary to what might be called a general impression as to the effect of variation in barometric pressure, the writer's investigations (subject, however, to further experimental proof beyond the limits of temperature of 35 deg. to 100 deg. fahr. and pressures much above 30 in. of mercury) have lead him to the definite conclusion that it is a mistake to claim any effect, even down to the limits of attainable vacuum, upon the amount of moisture in cotton or wool exposed thereto, beyond that of the rapidity at which the surrounding atmosphere and material can attain to a common temperature, and a regain state corresponding both thereto and the balancing amount of moisture present or available. In other words, it appears to the writer that for a given temperature and a constant relative humidity, the regain state will be found the same at all pressures.[1] These are important considerations in practical drying problems.

[1] Fig. 16 can be used to illustrate an imaginary experiment. Note on the chart that the 70-deg. temperature line, the 50 per cent relative-humidity line, the 4-grain curve of aqueous vapor per cubic foot, and the 13 per cent regain line intersect at the same point.

Now, suppose a small quantity of wool, say a pound (more or less), containing 4 grains of moisture over and above enough to equal a condition of 13 per cent regain, to be placed in a vessel, capable of enlargement, as by the movement of a piston in a cylinder, with a free-space content of 1 cu. ft. at the given temperature and relative humidity; and that this space be instantly enlarged to 2 cu. ft. The amount of moisture present in this space (the amount of air present does not alter the amount) if the wool were not there, nor any other source of moisture available, would be still only 4 grains, or 2 grains per cubic foot; but with the wool present, and enough heat available to evaporate the 4 extra grains contained in the wool and still maintain or recover the original temperature, this evaporation would promptly take place, leaving the material in the assumed state of equilibrium (13 per cent) with the surrounding space at the 70-deg. temperature and 50 per cent relative humidity. No air having been admitted, the sum of the pressures of the air and moisture will have become less than at the start, or, in other words, the condition will be one of partial vacuum.

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107 Within the limits of its application this is a simple corrollary to the mathematical statement of the general law of regain first announced by the writer in 1905 and subsequently confirmed and restated more accurately in 1911, and in the present paper, after further demonstration by a series of carefully controlled experiments on cotton and wool. In this formula the factor of pressure does not appear except in the ratio $e/E = H$, for relative humidity. It undoubtedly has an effect in the phenomenon of lag there referred to.

SPECIAL LINES

108 In Fig. 19 the position of the line labeled 8.5 per cent (the so-called standard regain for cotton) may be interpreted as showing the storehouse or mill conditions where any kind of cotton or cotton goods, not chemically affected by dyeing or other finishing, would be unlikely to lose or gain weight when testing to this standard at time of storage; that is, when the actual weight of 100 lb. of bone-dry (standard dry) material was 108½ lb.; on the other hand, if this amount of bone-dry material was found to weigh more or less than 108½ lb. the tendency would be to lose or gain, if sufficiently exposed; or vice versa, if the conditions of the room were either drier or moister, there would be a corresponding tendency to lose or gain weight from such a standard condition of the material.

109 Since cotton in the bale sometimes arrives at the mill in a condition testing as high as 16 per cent regain, which would mean that every bale whose corrected weight at 8½ per cent regain was 500 lb. would be weighing 534½ lb., the commercial importance of considering these conditions is obvious. Every such bale, if no claim for excess of moisture were made and allowed, would be costing the buyer, at 20 cents per lb., $6.90 a bale more than another containing the same amount of cotton weighing 500 lb. at 8½ per cent regain.[1]

110 On wool the several so-called standards are not uniform in all countries, but some of them are more definitely recognized and broadly utilized in actual commercial transactions than is the single cotton standard in any country. In the United States the standard condition of 15 per cent moisture regain may be said to be definitely established, by custom though not by law, for the selling

[1] For a description of some carefully made tests and of a practical method of obtaining a sufficiently accurate average result, see Report of Committee on Moisture in Baled Cotton, Trans. National Association Cotton Manufacturers, vol. 82, p. 262. Committee: Wm. D. Hartshorne, *Chairman*, Christopher P. Brooks, Louis Atwill Olney.

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of worsted tops, whether combed "dry" (that is, without oil) or combed with oil.

111 The amount of oil, or more correctly, the loss by careful scouring, is not so definitely standardized here as it is in Bradford, England. Even there, though a standard for scoured loss of 3½ per cent is recognized, it is not so carefully followed or insisted upon in trading as is their standard regain of 19 per cent moisture for oil-combed tops and 18¼ per cent for tops combed dry. However, since the equilibrium regain condition, where olive oil only is used and where no other hygroscopic material is present, depends alone upon the proportion of wool, it was shown by the writer in the April 1914 number of the Bulletin of the National Association of Wool Manufacturers that the 19 per cent standard on Bradford oil-combed tops means nearly 20 per cent when the moisture is calculated on the clean-wool content. Hence the emphasized line at 20 per cent regain in Fig. 18.

112 In the same manner it was there shown that 18¼ per cent for *yarn* made from tops combed with a Bradford standard scoured loss of 3.5 per cent would be 19 per cent on the clean-wool content. Hence the emphasis on the 19 per cent line.

113 The 18¼ per cent line stands on its own feet, so to speak, as being the condition at which dry-combed tops, and yarn spun from them, usually by the French system of spinning, are standardized and sold both in England and on the Continent.

114 Assuming the scoured loss on oil-combed tops in this country to be 3 per cent and the moisture regain 15 per cent, then the dry clean weight of wool in 100 lb. at standard condition would be approximately 84 lb. (as against the Bradford standard of 80.5 lb.) and, as figured on the clean-wool content, the 13 lb. of water (the loss from 100 lb. at 15 per cent regain) would be approximately 15.5 per cent. Hence the 15.5 per cent line, which shows by its position the corresponding atmospheric conditions of equilibrium for oil-combed tops, and the 15 per cent line for the dry-combed tops.

115 It cannot at present be said that any definite standard for moisture regain on cotton, manufactures of cotton, raw or scoured wool, worsted yarns, or other manufactures of wool except tops, or other textile materials except silk, is properly recognized in the trade in this country.[1]

[1] The testing of silk is a large feature in the valuable work done by the United States Conditioning and Testing Company, New York. See lower footnote on p. 1077.

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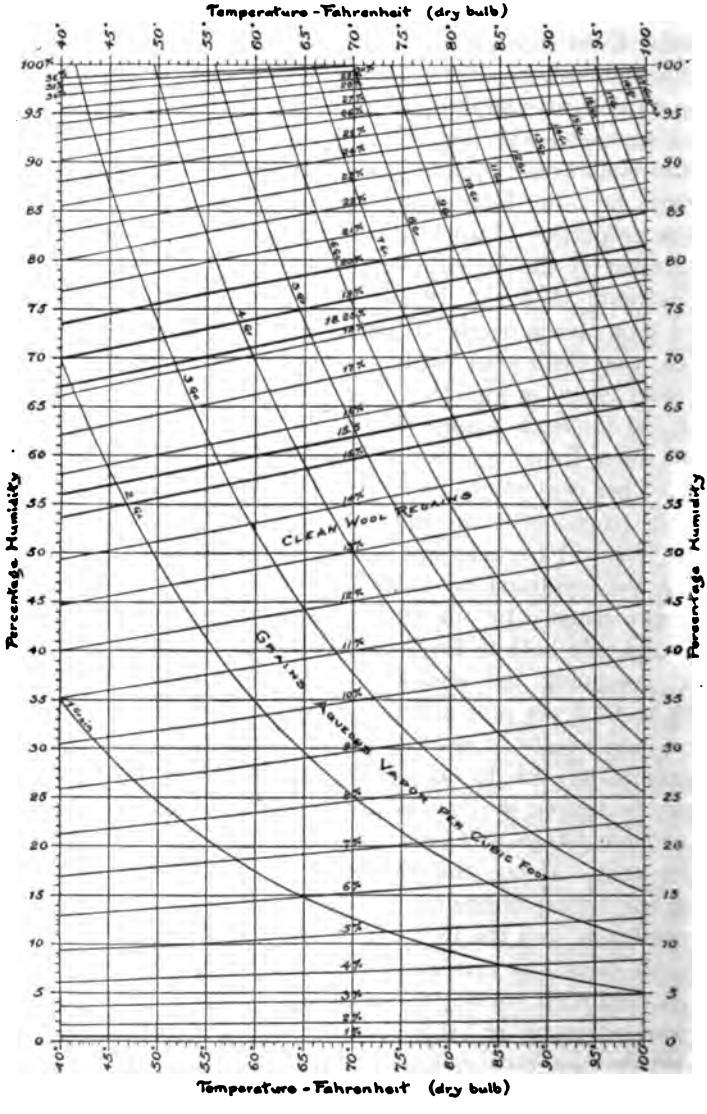

FIG. 18 UNIT-VARIATION REGAIN AND SPECIAL 15, 15½, 18½, 19 AND 20 PER CENT LINES, WOOL

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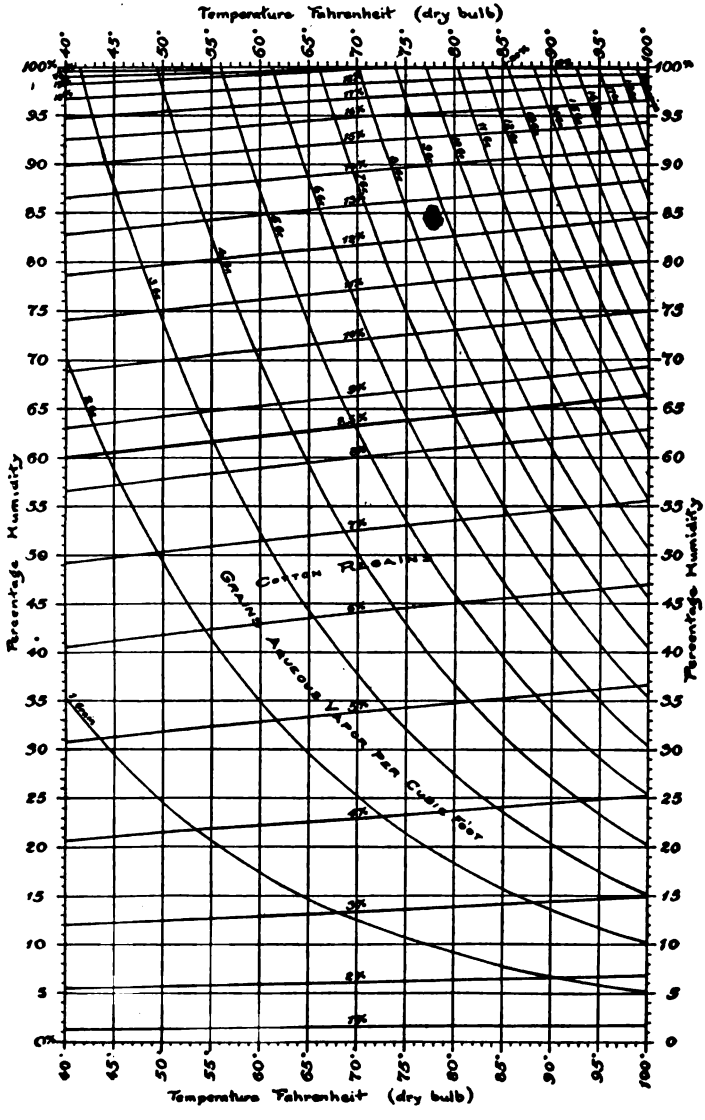

FIG. 19 UNIT-VARIATION REGAIN AND SPECIAL 8½ PER CENT LINE, COTTON

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116 There are many conflicting reasons for the lack of such standards here,[1] but none of them are insurmountable if the object be merely to establish a common standard by which to buy and sell, as has been the case with the somewhat less hygroscopic but still more valuable material, silk, for which the standard of 11 per cent regain is generally recognized all over the world and, indeed, was made such in France, both by commercial practice and by sanction of the French Government nearly seventy-five years ago.

[1] "The following regains for the various yarns were agreed upon at the International Congress held at Turin in 1875:

18¼ per cent for worsted
17 per cent for carded woolen
8½ per cent for cotton
12 per cent for flax and hemp
13¾ per cent for jute
13 per cent for shoddy.

the drying temperature to be 105 to 110 deg. cent.

"The above temperatures are equivalent to 221 to 230 deg. fahr.

"The standard for silk (11 per cent) was declared by the Lyons Chamber of Commerce on September 3, 1840, and received the French Government sanction by an order of April 23, 1841.

"The regain standards of the Bradford Conditioning House are as follows:

19 per cent for tops combed with oil
18¼ per cent for tops combed without oil
14 per cent for noils, ordinary
16 per cent for noils scoured or carbonized
18¼ per cent for worsted yarns
8½ per cent for cotton
11 per cent for silk
16 per cent for wool and waste
16 per cent for worsted and woolen cloths.

"The above series of standards have been accepted by all European Testing and Conditioning Houses, and no other competing standards can be said to exist, although higher standards are occasionally suggested." — Notes on Sampling and Testing (1913 edition), Manchester Chamber of Commerce.

In the above, there is an important omission of the standard for "washed wool" made use of by the Conditioning House at Mazamet, the center of the skin or pulled-wool industry in southern France. The regain allowed is 18 per cent figured on the scoured (dry) weight as obtained from tested samples. Curiously, it is not their custom to report the amount of loss (which must of necessity have been found on the samples tested) of anything but the moisture. The additional loss might be anywhere from 10 per cent to 20 per cent or more, but it is left to the judgment of the wool buyer to estimate this in each lot which he examines. It would appear that there is both a physical and a psychological reason for this.

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117 The most important reason for not adopting the English and Continental standards for wool here lies in the fact that it is more difficult to maintain indoor atmospheric conditions in our climate corresponding to such standards, and moreover, tops and yarns actually containing such amounts of moisture, if long stored unprotected from mildew, are likely to become seriously damaged.

118 In the writer's experience there is little such danger of damage at 15½ per cent on wool (15 per cent on oil stock) or 8½ per cent on cotton.[1] While it is true that for the best conditions of spinning it is better to have in the material an amount of moisture equal to, or possibly even greater than, the Bradford standards, in order to allow for necessary losses by evaporation and still maintain a humidity condition of spinning rooms at a point where electrical action in cold weather would be without material effect, yet this can be taken care of by the spinner himself, and need not involve the danger from mildew by long storage at Bradford standards in our warmer climate. However, with material worth anywhere from 50 cents to $2 per lb. or more, it is easy to see the commercial importance of knowing at what price 100 lb. of bone-dry material is being bought or sold, but it makes little difference, as a commercial transaction, whether the price be fixed on the basis of that 100 lb. weighing 110 lb., 115 lb., or even 120 lb., providing the standard is accepted, condition determined, and corrected weight billed up.

119 Figs. 15 to 19 will aid in an understanding of how and to what extent known climatic changes, either indoors or out, will tend to affect weight, but in the writer's opinion sufficient consideration has nowhere yet been given to determining the limitations as to strength, or elasticity, or measurement of textile materials under varying conditions of moisture content. More has been done perhaps on cotton than upon any other material. However, the function played by the element of twist in connection with length of staple in both cotton and wool, though in general terms well understood, is greatly affected by the relation of moisture content to surrounding conditions, especially in wool, in ways which are meas-

[1] Tops combed in Bradford and shipped to Japan under Bradford standard conditions are baled up with a mildew protective covering (the invention of a Japanese) which has proved very successful, not only in preventing a change in weight during transit or storage for use, but from all effects of the mildew plant whose roots though they may be growing on the outside do not penetrate this material.

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urable not only in quantity of product from a given machine, but also in its quality as required for subsequent use. These will be subjects for further papers.

AUTHOR'S NOTE

120 The writer recognizes that his development of the laws of regain is limited in its application to the accuracy of the data used for vapor pressures and vapor densities taken from the U. S. Weather Bureau Report.

The question has been asked, What would be the effect upon the statement of these laws, and the tabulated deductions for regain on cotton and wool, of using the corresponding data given by Marks and Davis or the still later deductions of Willis H. Carrier,[1] involving more complicated considerations? The writer's answer is: none of practical importance, as regards regain conditions within the limits of temperature experimented with. Possibly a more general statement depending upon the data of these authors and others could be devised to include conditions for temperatures beyond 100 deg. fahr., which might have practical importance on some problems of moisture content of materials. There is room here for further research.

[1] Rational Psychrometric Formulæ, W. H. Carrier, Trans.Am.Soc.M.E., vol. 33 (1911), p. 1005.

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APPENDIX

TABLE 2 OBSERVATIONS ON WORSTED FROM AUSTRALIAN MERINO WOOL AT 70 DEG. FAHR.

Regain at 19.8% humidity, %			Regain at 55.6% humidity, %			Regain at 88.47% humidity, %		
	7.01			14.18			23.02	
Skeins	7.04		Skeins	14.18		Skeins	23.04	
Nos. 44	7.01		Nos. 41	14.21		Nos. 51	23.26	
& 45	7.11	28.17	& 42	14.23		& 52	23.09	
	7.12			14.16			23.16	
Skeins	6.93			14.05	85.01		23.19	138.76
Nos. 51	7.09							
& 52	7.19	28.33		14.06			23.10	
	7.02		Skeins	14.15		Skeins	23.06	
Skeins	6.97		Nos. 49	14.05		Nos. 53	23.03	
Nos. 53	6.87		& 50	14.10		& 54	23.06	
& 54	7.02	27.88		14.15			23.15	
				14.06	84.59		23.08	138.48
Average.....		7.03	Average.....		14.13	Average.....		23.10

TABLE 3 OBSERVATIONS ON WORSTED FROM AUSTRALIAN MERINO WOOL AT 55.6 PER CENT HUMIDITY

Regain at 40° F., %			Regain at 55° F., %			Regain at 85° F., %			Regain at 100° F., %		
	15.22			14.93			13.41			13.03	
Skeins	15.37		Skeins	14.63		Skeins	13.73		Skeins	13.07	
Nos. 41	15.48		Nos. 41	14.88		Nos. 41	13.51		Nos. 41	12.99	
& 42	15.34		& 42	14.78		& 42	13.53		& 42	13.13	
	15.48			14.82			13.53			12.94	
	15.59	92.48		14.85	88.89		13.48	81.19		12.93	78.09
Skeins	15.29		Skeins	14.67		Skeins	13.58		Skeins	13.06	
Nos. 49	15.34		Nos. 49	14.65		Nos. 49	13.53		Nos. 49	12.93	
& 50	15.43		& 50	14.77		& 50	13.53		& 50	12.96	
	15.41			14.77			13.50			12.97	
	15.15			14.68			13.40			13.02	
	15.55	92.17		14.75	88.29		13.48	81.02		13.01	77.95
Average..		15.39	Average...		14.77	Average..		13.52	Average..		13.00

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TABLE 4 OBSERVATIONS ON SEA ISLAND COTTON AT 70 DEG. FAHR.

Regain at 19.64 per cent humidity, %			Regain at 55.21 per cent humidity, %			Regain at 88.45 per cent humidity, %		
	3.70			7.35			13.61	
Skeins	3.64		Skeins	7.35		Skeins	13.66	
11 and 12	3.66		7 and 8	7.30		7 and 8	13.52	
	3.56			7.40			13.70	
		14.56			29.40			54.79
	3.77			7.24			13.68	
Skeins	3.72		Skeins	7.35		Skeins	13.64	
9 and 10	3.69		9 and 10	7.22		9 and 10	13.76	
	3.67			7.40			13.96	
		14.85			29.21			55.06
Average.....		3.66	Average...		7.33	Average....		13.73

TABLE 5 VALUES OF *R*, *K*, *KR* AND *H* AS FOUND FROM EQUATION FOR 70-DEG. CURVE

For Sea Island Cotton

	R	*K*	*KR*	*H*[1]
Inferred, for A'.....	*0*	*0*	*0*	*0*
	1	59.0	59	1.53
	2	116.8	234	6.01
	3	172.3	517	13.29
Observed, for B'.....	*3.68*	*207.6*	*764*	*19.64*
	4	223.0	892	22.93
	5	263.1	1315	33.81
	6	285.7	1714	44.06
	7	292.7	2049	52.67
Observed, for C'.....	*7.33*	*293.0*	*2148*	*55.22*
	8	291.7	2335	60.03
	9	287.1	2583	66.40
	10	280.6	2806	72.13
	11	273.2	3005	77.25
	12	265.2	3182	81.80
	13	256.8	3339	85.84
Observed, for D'.....	*13.73*	*250.6*	*3441*	*88.45*
	14	243.3	3476	89.35
	15	239.5	3593	92.36
	16	230.6	3690	94.86
	17	221.6	3768	96.86
	18	212.6	3827	98.38
	19	204.4	3884	99.84
	20	194.3	3887	99.90
Inferred, for E'.....	*20.6*	*188.2*	*3890*	*100.00*

[1] Expressed as per cent.

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TABLE 6 VALUES OF *R*, *K*, *KR* AND *H* AS FOUND FROM EQUATION FOR 70-DEG. CURVE

For Worsted

	R	*K*	*KR*	*H*[1]
Inferred, for A	*0*	*0*	*0*	*0*
	1	19.2	19	0.50
	2	37.3	75	1.93
	3	54.4	163	4.20
	4	70.1	280	7.20
	5	84.6	423	10.87
	6	97.6	586	15.06
	7	109.2	764	19.64
Observed, for B	*7.05*	*109.6*	*770*	*19.80*
	8	119.4	955	24.55
	9	128.1	1153	29.64
	10	135.4	1354	34.81
	11	141.5	1556	40.00
	12	146.3	1756	45.14
	13	150.0	1950	50.13
	14	152.8	2139	55.00
Observed, for C	*14.18*	*153.1*	*2163*	*55.60*
	15	154.7	2320	59.64
	16	155.8	2493	64.09
	17	156.3	2657	68.30
	18	156.2	2812	72.29
	19	155.6	2956	76.00
	20	154.5	3090	79.44
	21	153.1	3215	82.65
	22	151.3	3329	85.58
	23	149.2	3432	88.23
Observed, for D	*23.10*	*149.0*	*3442*	*88.47*
	24	146.9	3526	90.64
	25	144.3	3607	92.73
	26	141.5	3679	94.58
	27	138.5	3739	96.12
	28	135.4	3791	97.45
	29	132.3	3837	98.64
	30	128.7	3861	99.25
	31	125.2	3881	99.77
	32	121.5	3888	99.95
Inferred, for E	*32.5*	*119.7*	*3890*	*100.00*

[1] Expressed as per cent.

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TABLE 7 WORSTED REGAIN, PER CENT

Per cent H	Deg. Fahr.													
	35	40	45	50	55	60	65	70	75	80	85	90	95	100
1	1.57	1.55	1.53	1.50	1.48	1.46	1.44	1.42	1.40	1.38	1.36	1.34	1.33	1.31
2	2.25	2.22	2.18	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.92	1.89	1.87
3	2.79	2.75	2.71	2.67	2.63	2.59	2.56	2.52	2.49	2.45	2.42	2.38	2.35	2.32
4	3.24	3.19	3.14	3.09	3.05	3.01	2.96	2.92	2.88	2.84	2.80	2.76	2.72	2.68
5	3.63	3.58	3.53	3.48	3.42	3.38	3.33	3.28	3.23	3.19	3.15	3.10	3.06	3.02
6	4.01	3.95	3.89	3.84	3.78	3.73	3.67	3.62	3.56	3.52	3.47	3.42	3.37	3.33
7	4.37	4.30	4.24	4.17	4.11	4.05	4.00	3.94	3.88	3.83	3.78	3.73	3.68	3.63
8	4.68	4.61	4.54	4.47	4.41	4.34	4.28	4.22	4.16	4.10	4.05	3.99	3.94	3.89
9	4.99	4.91	4.84	4.77	4.70	4.63	4.56	4.50	4.44	4.38	4.32	4.26	4.20	4.14
10	5.27	5.20	5.12	5.04	4.97	4.90	4.83	4.76	4.69	4.63	4.57	4.50	4.44	4.38
11	5.57	5.49	5.41	5.33	5.25	5.18	5.10	5.03	4.96	4.89	4.82	4.76	4.69	4.63
12	5.85	5.76	5.68	5.59	5.51	5.43	5.36	5.28	5.21	5.13	5.06	4.99	4.93	4.86
13	6.12	6.03	5.94	5.85	5.76	5.68	5.60	5.52	5.44	5.37	5.29	5.22	5.15	5.08
14	6.37	6.27	6.18	6.09	6.00	5.92	5.83	5.75	5.67	5.59	5.51	5.44	5.37	5.29
15	6.64	6.54	6.44	6.35	6.25	6.16	6.08	5.99	5.90	5.82	5.74	5.67	5.59	5.52
16	6.88	6.78	6.68	6.58	6.48	6.39	6.30	6.21	6.12	6.04	5.96	5.87	5.80	5.72
17	7.13	7.02	6.92	6.81	6.71	6.62	6.52	6.43	6.34	6.25	6.17	6.08	6.00	5.92
18	7.37	7.26	7.15	7.05	6.94	6.84	6.75	6.65	6.56	6.47	6.37	6.29	6.21	6.12
19	7.60	7.49	7.38	7.27	7.16	7.06	6.96	6.86	6.76	6.67	6.58	6.49	6.40	6.32
20	7.83	7.72	7.60	7.49	7.38	7.28	7.17	7.07	6.97	6.87	6.78	6.69	6.60	6.51
21	8.07	7.95	7.83	7.71	7.60	7.49	7.39	7.28	7.17	7.08	6.98	6.88	6.79	6.70
22	8.30	8.18	8.05	7.94	7.82	7.71	7.60	7.49	7.39	7.28	7.18	7.09	6.99	6.90
23	8.52	8.39	8.27	8.15	8.03	7.91	7.80	7.69	7.58	7.48	7.37	7.27	7.18	7.08
24	8.74	8.61	8.48	8.36	8.24	8.12	8.00	7.89	7.78	7.67	7.57	7.46	7.36	7.26
25	8.96	8.83	8.70	8.57	8.45	8.33	8.21	8.09	7.97	7.86	7.76	7.65	7.55	7.45
26	9.18	9.05	8.91	8.78	8.66	8.53	8.41	8.29	8.17	8.06	7.95	7.84	7.74	7.63
27	9.41	9.27	9.13	9.00	8.86	8.74	8.61	8.49	8.37	8.26	8.14	8.03	7.92	7.82
28	9.62	9.47	9.33	9.19	9.06	8.93	8.80	8.68	8.56	8.44	8.32	8.21	8.10	7.99
29	9.83	9.68	9.54	9.40	9.26	9.13	9.00	8.87	8.75	8.63	8.51	8.39	8.28	8.17
30	10.05	9.90	9.75	9.61	9.47	9.33	9.20	9.07	8.94	8.82	8.70	8.58	8.46	8.35
31	10.26	10.11	9 96	9.81	9.67	9.53	9.39	9.26	9.13	9.00	8.88	8.76	8.64	8.53
32	10.48	10.33	10.17	10.02	9.88	9 73	9.60	9.46	9.33	9.20	9.07	8.95	8.83	8.71

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33	10.69	10.53	10.37	10.22	10.08	9.93	9.78	9.65	9.52	9.38	9.25	9.13	9.01	8.88
34	10.90	10.74	10.58	10.43	10.27	10.13	9.98	9.84	9.70	9.57	9.44	9.31	9.18	9.06
35	11.12	10.96	10.80	10.64	10.48	10.33	10.18	10.04	9.90	9.76	9.63	9.50	9.37	9.24
36	11.34	11.17	11.00	10.84	10.68	10.53	10.38	10.23	10.09	9.95	9.81	9.68	9.55	9.42
37	11.55	11.37	11.20	11.04	10.88	10.72	10.57	10.42	10.27	10.13	9.99	9.86	9.72	9.59
38	11.76	11.58	11.41	11.24	11.08	10.92	10.76	10.61	10.46	10.32	10.18	10.04	9.90	9.77
39	11.98	11.80	11.62	11.45	11.29	11.12	10.97	10.81	10.66	10.51	10.37	10.23	10.09	9.95
40	12.19	12.01	11.83	11.65	11.48	11.32	11.16	11.00	10.85	10.70	10.54	10.41	10.26	10.13
41	12.41	12.22	12.04	11.87	11.69	11.53	11.36	11.20	11.04	10.89	10.74	10.59	10.45	10.31
42	12.62	12.43	12.25	12.07	11.89	11.72	11.55	11.39	11.23	11.07	10.92	10.77	10.63	10.49
43	12.84	12.65	12.46	12.28	12.10	11.93	11.76	11.59	11.43	11.27	11.11	10.96	10.82	10.67
44	13.05	12.86	12.67	12.48	12.30	12.12	11.95	11.78	11.62	11.45	11.30	11.14	10.99	10.85
45	13.26	13.06	12.87	12.68	12.50	12.32	12.14	11.97	11.80	11.64	11.48	11.32	11.17	11.02
46	13.48	13.28	13.09	12.89	12.71	12.52	12.34	12.17	12.00	11.83	11.67	11.51	11.36	11.20
47	13.71	13.50	13.30	13.11	12.91	12.73	12.55	12.37	12.20	12.03	11.86	11.70	11.54	11.39
48	13.93	13.72	13.52	13.32	13.12	12.93	12.75	12.57	12.39	12.22	12.05	11.89	11.73	11.57
49	14.15	13.94	13.73	13.53	13.33	13.14	12.95	12.77	12.59	12.42	12.25	12.08	11.92	11.76
50	14.37	14.16	13.95	13.74	13.54	13.35	13.16	12.97	12.79	12.61	12.44	12.27	12.10	11.94
51	14.60	14.39	14.17	13.96	13.76	13.56	13.37	13.18	13.00	12.82	12.64	12.47	12.30	12.13
52	14.83	14.60	14.39	14.18	13.97	13.77	13.57	13.38	13.19	13.01	12.83	12.66	12.49	12.32
53	15.05	14.82	14.60	14.39	14.18	13.97	13.77	13.58	13.39	13 20	13.02	12.85	12.67	12.50
54	15.28	15.05	14.83	14.61	14.40	14.19	13.99	13.79	13.60	13.41	13.22	13.04	12.87	12.70
55	15.51	15.28	15.05	14.83	14.62	14.41	14.20	14.00	13.80	13.61	13.43	13.24	13.06	12.89
56	15.75	15.51	15.28	15.06	14.84	14.62	14.41	14.21	14.01	13.82	13.63	13.44	13.26	13.08
57	15.99	15 75	15.52	15.29	15.07	14 85	14.64	14.43	14.23	14.03	13.84	13.65	13.47	13.28
58	16.22	15.98	15.74	15.51	15.28	15.06	14.85	14.64	14.44	14.23	14.04	13.85	13.66	13.48
59	16.47	16.22	15.98	15.74	15.51	15.29	15.07	14.86	14.65	14.45	14.25	14.06	13.87	13.68
60	16.71	16.46	16.21	15.98	15.74	15.52	15.30	15.08	14.87	14.66	14.46	14.26	14.07	13.88
61	16.95	16.70	16.45	16.21	15.97	15.74	15.52	15.30	15.09	14.88	14.67	14.47	14.28	14.09
62	17.20	16.94	16.69	16.44	16.20	15.97	15.74	15.52	15.30	15.09	14.88	14.68	14.48	14.29
63	17.45	17.19	16.94	16.69	16.45	16.21	15.98	15.75	15.53	15.31	15.10	14.90	14.70	14.50
64	17.70	17.44	17.18	16.93	16.68	16.44	16.21	15.98	15.76	15.54	15.32	15.12	14.91	14.71
65	17.96	17.69	17.43	17.17	16.92	16.68	16.44	16.21	15.98	15.76	15.54	15.33	15.13	14.92
66	18.23	17.95	17.69	17.43	17.17	16.93	16.69	16.45	16.22	15.99	15.77	15.56	15.35	15.14
67	18.49	18.22	17.95	17.68	17.43	17.17	16.93	16.69	16.46	16.23	16.00	15.79	15.57	15.37

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TABLE 7 WORSTED REGAIN, PER CENT (Continued)

Per cent H	Deg. Fahr.													
	35	40	45	50	55	60	65	70	75	80	85	90	95	100
68	18.76	18.48	18.20	17.94	17.68	17.42	17.17	16.93	16.69	16.46	16.24	16.01	15.80	15.59
69	19.03	18.74	18.46	18.19	17.93	17.67	17.42	17.17	16.93	16.69	16.47	16.24	16.02	15.81
70	19.30	19.01	18.73	18.46	18.19	17.93	17.67	17.42	17.18	16.94	16.71	16.48	16.26	16.04
71	19.58	19.29	19.00	18.72	18.45	18.18	17.92	17.67	17.42	17.18	16.94	16.71	16.49	16.27
72	19.87	19.57	19.28	19.00	18.72	18.45	18.19	17.93	17.68	17.43	17.19	16.96	16.73	16.51
73	20.16	19.85	19.56	19.28	18.99	18.72	18.46	18.19	17.94	17.69	17.44	17.21	16.97	16.75
74	20.45	20.15	19.85	19.56	19.27	19.00	18.72	18.46	18.20	17.95	17.70	17.46	17.23	17.00
75	20.75	20.44	20.14	19.84	19.56	19.27	19.00	18.73	18.47	18.21	17.96	17.72	17.48	17.24
76	21.05	20.74	20.43	20.13	19.84	19.55	19.28	19.00	18.73	18.47	18.22	17.97	17.73	17.49
77	21.36	21.04	20.73	20.43	20.13	19.84	19.56	19.28	19.01	18.75	18.49	18.24	17.99	17.75
78	21.68	21.36	21.04	20.73	20.43	20.14	19.85	19.57	19.30	19.03	18.77	18.51	18.26	18.02
79	22.02	21.69	21.37	21.05	20.75	20.45	20.15	19.87	19.59	19.32	19.05	18.79	18.54	18.29
80	22.35	22.01	21.69	21.37	21.06	20.76	20.46	20.17	19.89	19.61	19.34	19.08	18.82	18.57
81	22.69	22.35	22.02	21.70	21.38	21.07	20.77	20.48	20.19	19.91	19.64	19.37	19.11	18.85
82	23.05	22.70	22.37	22.04	21.72	21.40	21.10	20.80	20.51	20.22	19.95	19.67	19.41	19.15
83	23.40	23.05	22.71	22.38	22.05	21.73	21.42	21.12	20.82	20.54	20.25	19.98	19.71	19.44
84	23.77	23.41	23.06	22.73	22.40	22.07	21.76	21.45	21.15	20.86	20.57	20.29	20.02	19.75
85	24.16	23.79	23.44	23.10	22.76	22.43	22.11	21.80	21.49	21.22	20.91	20.62	20.34	20.07
86	24.54	24.18	23.82	23.47	23.13	22.79	22.47	22.15	21.84	21.54	21.24	20.95	20.67	20.39
87	24.95	24.58	24.21	23.86	23.51	23.17	22.84	22.52	22.20	21.90	21.59	21.30	21.01	20.73
88	25.39	25.01	24.63	24.27	23.92	23.57	23.24	22.91	22.59	22.28	21.97	21.67	21.38	21.09
89	25.84	25.45	25.08	24.71	24.35	24.00	23.65	23.32	22.99	22.67	22.36	22.06	21.76	21.47
90	26.29	25.90	25.52	25.14	24.78	24.42	24.07	23.73	23.40	23.07	22.76	22.45	22.14	21.85
91	26.78	26.38	25.99	25.61	25.23	24.87	24.52	24.17	23.83	23.50	23.18	22.86	22.55	22.25
92	27.31	26.90	26.50	26.12	25.74	25.37	25.00	24.65	24.30	23.97	23.64	23.32	23.00	22.69
93	27.87	27.45	27.04	26.65	26.26	25.88	25.51	25.15	24.80	24.45	24.12	23.79	23.47	23.15
94	28.47	28.04	27.62	27.22	26.82	26.44	26.06	25.69	25.33	24.98	24.64	24.30	23.97	23.65
95	29.11	28.67	28.25	27.83	27.43	27.03	26.65	26.27	25.90	25.54	25.19	24.85	24.51	24.19
96	29.83	29.38	28.95	28.52	28.11	27.70	27.31	26.92	26.54	26.17	25.82	25.46	25.12	24.78
97	30.65	30.19	29.74	29.30	28.88	28.46	28.06	27.66	27.27	26.89	26.52	26.16	25.81	25.47
98	31.64	31.06	30.60	30.15	29.71	29.29	28.87	28.46	28.06	27.67	27.29	26.92	26.56	26.20
99	32 79	32.30	31.82	31.35	30.89	30.45	30.01	29 59	29.18	28.77	28.38	27.99	27.61	27 24
100	36.01	35 47	34 95	34.43	33 93	33 44	32 97	32.50	32.04	31.60	31.17	30.74	30.33	29 92

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TABLE 8 COTTON REGAIN, PER CENT

Per cent *H*	Deg. Fahr.													
	35	40	45	50	55	60	65	70	75	80	85	90	95	100
1	0.74	0.72	0.72	0.72	0.71	0.70	0.70	0.69	0.68	0.68	0.67	0.66	0.66	0.65
2	1.20	1.19	1.18	1.16	1.15	1.14	1.13	1.12	1.11	1.10	1.09	1.08	1.07	1.06
3	1.43	1.42	1.41	1.39	1.38	1.37	1.35	1.34	1.33	1.32	1.30	1.29	1.28	1.27
4	1.67	1.65	1.64	1.62	1.61	1.59	1.57	1.56	1.55	1.53	1.52	1.50	1.49	1.48
5	1.91	1.89	1.87	1.85	1.83	1.81	1.80	1.78	1.76	1.74	1.73	1.72	1.70	1.68
6	2.14	2.12	2.10	2.08	2.06	2.04	2.02	2.00	1.98	1.96	1.94	1.93	1.91	1.89
7	2.29	2.27	2.25	2.22	2.20	2.18	2.16	2.14	2.12	2.10	2.08	2.06	2.04	2.03
8	2.43	2.41	2.38	2.36	2.34	2.31	2.29	2.27	2.26	2.24	2.21	2.19	2.16	2.15
9	2.58	2.55	2.53	2.51	2.48	2.46	2.43	2.41	2.39	2.36	2.34	2.32	2.30	2.28
10	2.72	2.70	2.68	2.65	2.62	2.60	2.57	2.55	2.53	2.50	2.48	2.46	2.44	2.41
11	2.87	2.84	2.81	2.79	2.76	2.73	2.71	2.68	2.65	2.63	2.61	2.58	2.56	2.54
12	3.01	2.98	2.95	2.92	2.89	2.86	2.84	2.81	2.78	2.76	2.73	2.70	2.68	2.65
13	3.16	3.13	3.10	3.07	3.04	3.01	2.98	2.95	2.92	2.89	2.87	2.84	2.82	2.79
14	3.29	3.26	3.22	3.19	3.16	3.13	3.10	3.07	3.04	3.01	2.99	2.96	2.93	2.91
15	3.41	3.37	3.34	3.30	3.27	3.24	3.21	3.18	3.15	2.12	3.09	3.06	3.04	3.01
16	3.51	3.48	3.44	3.41	3.38	3.34	3.31	3.28	3.25	3.22	3.19	3.16	3.13	3.10
17	3.63	3.59	3.56	3.52	3.49	3.46	3.42	3.39	3.36	3.33	3.30	3.27	3.24	3.21
18	3.74	3.70	3.66	3.63	3.59	3.56	3.52	3.49	3.47	3.43	3.39	3.36	3.33	3.30
19	3.84	3.81	3.77	3.73	3.69	3.66	3.62	3.59	3.55	3.52	3.49	3.46	3.43	3.40
20	3.93	3.92	3.88	3.85	3.81	3.77	3.74	3.70	3.67	3.64	3.60	3.57	3.53	3.50
21	4.07	4.03	3.99	3.95	3.92	3.87	3.83	3.80	3.76	3.73	3.70	3.66	3.63	3.60
22	4.19	4.14	4.10	4.06	4.02	3.99	3.95	3.91	3.88	3.84	3.80	3.77	3.73	3.70
23	4.29	4.25	4.21	4.17	4.13	4.13	4.05	4.01	3.97	3.94	3.90	3.86	3.83	3.79
24	4.39	4.35	4.30	4.26	4.22	4.18	4.14	4.10	4.06	4.02	3.99	3.95	3.92	3.88
25	4.49	4.44	4.40	4.35	4.31	4.27	4.23	4.19	4.15	4.11	4.07	4.04	4.00	3.97
26	4.58	4.54	4.49	4.45	4.40	4.36	4.32	4.28	4.24	4.20	4.16	4.12	4.09	4.05
27	4.68	4.63	4.59	4.54	4.50	4.45	4.41	4.37	4.33	4.29	4.25	4.21	4.17	4.14
28	4.79	4.74	4.69	4.65	4.60	4.56	4.51	4.47	4.43	4.39	4.35	4.31	4.27	4.23
29	4.88	4.83	4.79	4.74	4.69	4.65	4.60	4.56	4.52	4.48	4.43	4.39	4.35	4.32
30	4.98	4.93	4.88	4.83	4.79	4.74	4.69	4.65	4.61	4.56	4.52	4.48	4.44	4.40
31	5.08	5.02	4.97	4.93	4.88	4.83	4.79	4.74	4.70	4.65	4.61	4.57	4.53	4.49
32	5.17	5.12	5.07	5.02	4.97	4.92	4.88	4.83	4.78	4.74	4.70	4.65	4.61	4.57

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TABLE 8 COTTON REGAIN, PER CENT (Continued)

Per cent H	Deg. Fahr.													
	35	40	45	50	55	60	65	70	75	80	85	90	95	100
33	5.28	5.23	5.17	5.12	5.07	5.02	4.98	4.93	4.88	4.84	4.79	4.75	4.71	4.66
34	5.38	5.32	5.27	5.22	5.17	5.12	5.07	5.02	4.97	4.93	4.88	4.84	4.79	4.75
35	5.48	5.43	5.37	5.32	5.27	5.22	5.17	5.12	5.07	5.03	4.98	4.93	4.89	4.85
36	5.58	5.52	5.47	5.41	5.36	5.31	5.26	5.21	5.16	5.11	5.07	5.02	4.98	4.93
37	5.69	5.63	5.57	5.52	5.46	5.41	5.36	5.31	5.26	5.21	5.16	5.12	5.07	5.03
38	5.79	5.73	5.68	5.62	5.57	5.51	5.46	5.41	5.36	5.31	5.26	5.21	5.17	5.12
39	5.90	5.84	5.78	5.73	5.67	5.62	5.56	5.51	5.46	5.41	5.36	5.31	5.26	5.21
40	6.00	5.94	5.88	5.82	5.76	5.71	5.65	5.60	5.55	5.50	5.45	5.40	5.35	5.30
41	6.10	6.04	5.98	5.92	5.87	5.81	5.75	5.70	5.65	5.59	5.54	5.49	5.44	5.39
42	6.21	6.15	6.09	6.03	5.97	5.91	5.86	5.80	5.75	5.69	5.64	5.59	5.54	5.49
43	6.31	6.25	6.19	6.13	6.07	6.01	5.96	5.90	5.84	5.79	5.74	5.69	5.63	5.58
44	6.43	6.36	6.30	6.24	6.18	6.12	6.06	6.00	5.94	5.89	5.84	5.78	5.73	5.68
45	6.54	6.48	6.41	6.35	6.29	6.23	6.17	6.11	6.05	6.00	5.94	5.89	5.83	5.78
46	6.67	6.60	6.54	6.48	6.41	6.35	6.29	6.23	6.17	6.11	6.06	6.03	5.95	5.90
47	6.78	6.72	6.65	6.59	6.53	6.46	6.40	6.34	6.28	6.22	6.17	6.11	6.05	6.00
48	6.92	6.85	6.78	6.71	6.65	6.58	6.52	6.46	6.40	6.34	6.28	6.23	6.17	6.11
49	7.04	6.97	6.90	6.83	6.76	6.70	6.63	6.57	6.51	6.45	6.39	6.33	6.27	6.22
50	7.16	7.09	7.02	6.95	6.89	6.82	6.75	6.69	6.63	6.56	6.51	6.45	6.39	6.33
51	7.29	7.22	7.15	7.08	7.01	6.94	6.88	6.81	6.75	6.69	6.62	6.56	6.50	6.44
52	7.41	7.34	7.26	7.19	7.12	7.05	6.99	6.92	6.86	6.79	6.73	6.64	6.61	6.55
53	7.54	7.46	7.39	7.32	7.25	7.18	7.11	7.04	6.97	6.91	6.85	6.78	6.72	6.66
54	7.69	7.61	7.54	7.46	7.39	7.32	7.25	7.18	7.11	7.05	6.98	6.92	6.85	6.79
55	7.84	7.76	7.68	7.61	7.53	7.46	7.39	7.32	7.25	7.18	7.12	7.05	6.99	6.92
56	7.99	7.91	7.83	7.75	7.68	7.60	7.53	7.46	7.39	7.32	7.25	72.18	7.12	7.06
57	8.13	8.05	7.97	7.89	7.81	7.74	7.66	7.59	7.52	7.45	7.38	7.31	7.25	7.18
58	8.27	8.19	8.11	8.03	7.96	7.88	7.80	7.73	7.66	7.59	7.52	7.45	7.38	7.32
59	8.42	8.33	8.25	8.17	8.09	8.01	7.94	7.86	7.79	7.71	7.64	7.57	7.50	7.44
60	8.57	8.48	8.40	8.31	8.23	8.15	8.08	8.00	7.93	7.85	7.78	7.71	7.64	7.57
61	8.74	8.65	8.56	8.48	8.40	8.32	8.24	8.16	8.08	8.01	7.93	7.86	7.79	7.72
62	8.90	8.81	8.72	8.64	8.55	8.47	8.39	8.31	8.23	8.16	8.08	8.01	7.93	7.86
63	9.07	8.98	8.89	8.80	8.72	8.63	8.55	8.47	8.39	8.31	8.24	8.16	8.09	8.02
64	9.23	9.14	9.05	8.96	8.87	8.79	8.70	8.62	8.54	8.46	8.38	8.31	8.23	8.15

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65	9.40	9.31	9.22	9.13	9.04	8.95	8.86	8.78	8.70	8.62	8.54	8.46	8.38	8.31
66	9.57	9.48	9.38	9.29	9.20	9.11	9.03	8.94	8.86	8.77	8.69	8.61	8.54	8.46
67	9.74	9.65	9.55	9.46	9.37	9.28	9.19	9.10	9.02	8.93	8.85	8.77	8.69	8.61
68	9.94	9.84	9.74	9.64	9.55	9.46	9.37	9.28	9.19	9.11	9.03	8.94	8.86	8.78
69	10.12	10.02	9.92	9.82	9.73	9.63	9.54	9.45	9.36	9.28	9.18	9.11	9.03	8.94
70	10.31	10.21	10.11	10.01	9.91	9.82	9.72	9.63	9.54	9.45	9.36	9.28	9.20	9.11
71	10.49	10.39	10.29	10.19	10.09	9.99	9.89	9.80	9.71	9.62	9.53	9.44	9.35	9.27
72	10.69	10.58	10.48	10.37	10.27	10.17	10.08	9.98	9.89	9.80	9.71	9.62	9.53	9.44
73	10.89	10.78	10.67	10.57	10.47	10.36	10.27	10.17	10.08	9.98	9.89	9.80	9.71	9.62
74	11.10	10.99	10.88	10.78	10.67	10.57	10.47	10.37	10.27	10.17	10.08	9.99	9.90	9.81
75	11.31	11.19	11.08	10.98	10.87	10.76	10.66	10.56	10.46	10.37	10.27	10.18	10.08	9.99
76	11.52	11.41	11.29	11.18	11.07	10.97	10.86	10.76	10.66	10.56	10.46	10.37	10.26	10.18
77	11.72	11.61	11.49	11.38	11.27	11.16	11.05	10.95	10.85	10.75	10.65	10.55	10.46	10.36
78	11.96	11.84	11.72	11.61	11.50	11.39	11.28	11.17	11.06	10.96	10.86	10.76	10.67	10.57
79	12.19	12.06	11.94	11.83	11.71	11.60	11.49	11.38	11.27	11.17	11.07	10.96	10.87	10.77
80	12.42	12.30	12.17	12.06	11.94	11.82	11.71	11.60	11.49	11.38	11.28	11.18	11.08	10.98
81	12.66	12.53	12.41	12.28	12.16	12.05	11.93	11.82	11.71	11.60	11.49	11.39	11.29	11.19
82	12.90	12.77	12.65	12.52	12.40	12.28	12.16	12.05	11.94	11.83	11.72	11.61	11.51	11.40
83	13.17	13.04	12.91	12.78	12.66	12.54	12.42	12.30	12.19	12.07	11.96	11.85	11.75	11.64
84	13.43	13.29	13.16	13.03	12.91	12.78	12.66	12.54	12.42	12.30	12.19	12.08	11.97	11.87
85	13.70	13.55	13.42	13.29	13.16	13.04	12.91	12.79	12.67	12.55	12.44	12.32	12.21	12.10
86	13.97	13.83	13.70	13.56	13.43	13.30	13.17	13.05	12.93	12.81	12.69	12.58	12.46	12.35
87	14.27	14.13	13.99	13.85	13.72	13.59	13.46	13.33	13.21	13.08	12.96	12.84	12.73	12.62
88	14.58	14.44	14.30	14.15	14.02	13.88	13.75	13.62	13.49	13.37	13.24	13.12	13.01	12.89
89	14.88	14.74	14.59	14.45	14.31	14.17	14.03	13.90	13.77	13.64	13.52	13.40	13.27	13.15
90	15.23	15.07	14.92	14.78	14.63	14.49	14.36	14.22	14.09	13.96	13.83	13.70	13.58	13.46
91	15.58	15.42	15.27	15.12	14.97	14.83	14.69	14.55	14.41	14.28	14.15	14.02	13.89	13.77
92	15.95	15.79	15.63	15.48	15.33	15.19	15.04	14.90	14.76	14.62	14.49	14.36	14.23	14.10
93	16.36	16.20	16.04	15.88	15.73	15.57	15.43	15.28	15.14	15.00	14.86	14.72	14.59	14.46
94	16.82	16.65	16.49	16.33	16.17	16.01	15.86	15.71	15.56	15.42	15.28	15.14	15.00	14.87
95	17.27	17.10	16.93	16.76	16.60	16.44	16.28	16.13	15.98	15.83	15.69	15.54	15.40	15.26
96	17.74	17.57	17.39	17.22	17.05	16.89	16.73	16.57	16.42	16.26	16.11	15.97	15.82	15.68
97	18.30	18.12	17.94	17.76	17.59	17.42	17.25	17.09	16.93	16.77	16.62	16.47	16.32	16.17
98	19.01	18.82	18.63	18.45	18.27	18.09	17.92	17.75	17.58	17.42	17.26	17.10	16.95	16.80
99	19.72	19.53	19.33	19.14	18.96	18.77	18.60	18.42	18.25	18.08	17.91	17.75	17.59	17.43
100	22.07	21.84	21.62	21.41	21.20	21.00	20.80	20.60	20.41	20.22	20.03	19.85	19.67	19.50

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DISCUSSION

WALTER M. KIDDER (written). It would seem that the author's investigations and his achievement in defining the law governing the regain of moisture in textile fibers are of the greatest practical value to the manufacturer. Hitherto this subject has been appreciated by few, and has received consideration only to a meager extent by the average manufacturer.

The author raises but does not answer one question that is of the greatest importance because of the magnitude of the cotton industry in this country, namely, whether or not it is of advantage *to increase* the humidity of the air *in the successive processes* of manufacturing. It is a matter of importance to have this determined authoritatively.

The effect upon quality which the author shows results from varying conditions of moisture, constitutes a powerful argument for the maintenance, in each department, of uniformity of that particular condition which is most advantageous. To accomplish this in practice calls for intelligent application of the law that he has enunciated, and which the tables and charts presented by Mr. Hartshorne express in practical terms.

It also requires the exercise of engineering skill in many cases, for the flow of air currents within some factories extends throughout the entire structure. Differences in degree of humidity in different departments are difficult to control because of the freedom of circulation of air. It is difficult even to maintain uniformity in all parts of one room under the best conditions unless windows are sealed, doors are exceptionally tight and kept closed, and a thoroughly efficient ventilating system exists.

The possibilities of controlling humidity to greater advantage than in the past, as pointed out by Mr. Hartshorne, will open a new vision to most manufacturers of fabrics, especially in the cotton industry.

It is in such directions that progress, in the larger sense of the term, is to be expected in the future development of the art of textile manufacturing, for this matter is wholly practical and within the ability to achieve of every mill man who is determined to utilize every favorable factor.

WILLIS H. CARRIER thought that the author had gone into the subject with extreme thoroughness, and that the paper was a contribu-

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tion to the subject which would be permanent, largely because of the methods he had adopted.

The subject, however, had a very much wider bearing on paper. It was very important, he thought, perhaps, even more important than in the case of textiles, because in the subsequent treatment of paper and sizing and calendering the moisture content had to be procured with great accuracy for the best results. The same was true of tobacco and practically all hygroscopic substances where moisture content was important in the process.

There was one product he had in mind where the installation was bad, the material was wet, and they wanted to dry it down to 10 per cent moisture. But if they had sold it on the basis of 10 per cent moisture, it would have been at a loss, so finally the moisture was reduced to 0.25 per cent, which was made possible by his knowledge of the laws enunciated by Mr. Hartshorne. That was a very important application, for that one-half or one per cent they got in the week's production, something like $100,000, meant $1000 or so.

As to the law of regain, he looked upon it as the fundamental physical idea underlying the fact that material in the air in a certain percentage of moisture would have a certain regain, as the vapor pressure of the moisture in the material and the moisture in the air must be equal in order to have an equilibrium, and vapor pressures of the moisture in the material were dependent upon its hygroscopic action as the vapor pressure was reduced. If the material was saturated the vapor pressure would then correspond practically to that of free water, while if it was at another degree of saturation it would have less moisture. The vapor pressure was reduced by a certain definite percentage which, as Mr. Hartshorne pointed out, varied somewhat with the temperature.

These effects of differences in vapor pressure were very important in calculating rates of drying which occurred in various hygroscopic substances, and it would be desirable if Mr. Hartshorne would carry out his investigations at higher temperatures — temperatures beyond 100 deg. — where a great deal of the drying was done, in order that the laws could be investigated there as well as in the normal temperatures of the room.

THE AUTHOR, in closing, thanked Mr. Carrier for his comments. The question of the relation to drying, he thought, was an exceedingly important one, and he had mentioned it in the paper in several places as being affected in ways which might not be understood. That

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subject needed more investigation and he would be very glad to undertake it if he had a research laboratory available.

Referring to Mr. Kidder's communication, the question which was alluded to as having been raised but not answered the author agreed was very important, and he was of the opinion that it needed careful investigation under practically workable conditions, with complete understanding and controlled knowledge of results, to demonstrate what are the best obtainable effects both as to quality and quantity of product. It could be done, and for the benefit of the cotton industry it ought to be done authoritatively.

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No. 1627

THE WOMAN WORKER [1]

By John W. Upp, Schenectady, N. Y.
Member of the Society

THIS paper has been prepared as a record of the experience with the employment of women in one large manufacturing establishment under the changed industrial situation brought about by war conditions.

2 It is in fact only because the results thus far accomplished have been so encouraging and have given so much promise of future possibilities, that it seems advisable to bring those results to the attention of the members of this Society, for each woman that has been assigned and trained has released or helped to release a man for military duty.

3 Immediately following the commencement of hostilities in 1914 the demand for industrial workers began to increase, growing in intensity from month to month until the present, and will continue to increase until the war is ended.

4 In 1915–1916 it was evident that the skilled-labor market could not meet the great drain being made upon it. Then attempt was made to increase the working force to the proper point by employing large numbers of unskilled boys and men, who were first put to work in regular training schools under the supervision of experienced instructors. More or less beneficial increase resulted from this plan. But even these unusual methods failed in 1917 and there was immediate need of finding a new source of labor supply.

5 We of course knew of the magnificent manner in which the women of Europe had responded to the needs of the warring nations, yet we did not quickly take advantage of that knowledge, for we had always felt and still feel that except for office work or for lighter assembly and machine work where deftness of hand is of advantage

[1] This paper was discussed together with paper No. 1628 on Influence of Environment on the Woman Worker, by C. B. Lord. The discussion follows Mr. Lord's paper.

Presented at the Annual Meeting, December 1917, of The American Society of Mechanical Engineers.

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and where range of operations is within the admitted scope of woman's ability, she should not be considered in any of our plans for increasing productive capacity. But the need became so great, and there was such an earnest desire on the part of the women to relieve the men for the important military work for which they alone are fitted, that it became almost a duty to give serious consideration to the employment of women on work which had heretofore been taken care of by men exclusively.

6 Now the situation has become particularly acute because, coincident with the withdrawal of our men for military service and as a result of it, the Government's demands for manufacturing materials which have heretofore been produced by the men now assigned to military duty have largely increased.

7 Early in 1917 it was necessary to materially increase our manufacturing facilities in one line of work in which the writer is particularly interested. It was evident that we could not obtain enough men employees to operate the equipment which was purchased for these increased facilities; we could see that this lack of sufficient men employees would continue and increase rather than decrease our difficulties; and we knew we could obtain men for our facilities only if we withdrew them from other manufacturing departments or companies which were occupied on actual or related Government work. After thoughtful consideration we decided to make a definite attempt to use women operatives instead of men on all classes of machine work. Our plans were made accordingly, and the accompanying photographs will give you at least a little conception of the work that these women are doing for us.

8 In our minds, and in yours no doubt, there has been a feeling that women are not suited to operate complicated machine tools or to do the work that is required in a modern and high-grade machine shop.

9 Thus the solution of the first problem, What can a woman do? would determine the measure of her value to us. The answer is extremely interesting and satisfactory, for we have found women under proper conditions and with proper training almost, if not quite, the equal of men on the work to which the women have been assigned.

10 We have been much surprised at woman's strength and endurance and are now willing and ready to assign her to duties which were until recently assumed to be entirely beyond the scope of her ability. She is remarkably quick to learn. With only a short intensive instruction many women are working at duties

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which we would only give to apprentices of two or three years' training.

11 We have found, however, that it is necessary to recognize some fundamental difficulties if women are employed in these unusual occupations. In considering her ability to successfully withstand work in the factory, it should be remembered that a woman is not so strongly built as a man, that she is not so tall, that her reach is not so great, that she cannot stand so long, that she is unsuitable for the lifting and carrying of heavy weights, and that she must have a great many conveniences that men do not require. Thus it has been necessary in all our machine operations to change our methods of handling the work. This is so arranged and the carrying trays so constructed that it is impossible for a woman to obtain a load that is greater than 50 pounds, except where the size of an individual piece makes such a limit impossible. Stools or chairs are provided where possible and short rest periods are found advantageous in many cases.

12 All the states have quite stringent regulations in reference to rest rooms and hours of employment for women. We have always felt that it was desirable not only to live up to the letter of such laws but to provide facilities beyond those which were required, because most encouraging responses have been made when we provided additional facilities and conveniences.

13 We do not feel that any employer should encourage women to work in his shops unless the conditions are suitable for such employment, and that a very serious error will be made if employers put women to work in the machine shops under conditions which men are willing to endure.

14 In hiring women, especially for tasks which are new to them, several points should receive their proper share of consideration so that both the company and the employee may benefit by the partnership.

15 Careful attention must be given to the character of the women employed and more thorough investigation must be made of their references than in the case of men, for the employment of one undesirable woman will frequently destroy the usefulness of a large department. All the women working in any section must be acceptable to the other women or resignations with or without explanation will be apt to take place rapidly.

16 We also found early in our experience that women between the ages of 18 and 31 were more adaptable and learned more quickly

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than those who were younger or older — those who were younger than 18 not having reached a period of physical development which warranted their undertaking strenuous factory work, and those who were older than 31 being so fixed in their habits that they did not learn quickly enough to suit our purpose. In this experience, however, the employment of women has not differed materially from what it would be if we were employing men under the same conditions, for it is probable that if we completely changed the environment of men they would not be easy to instruct unless they were within the age limits specified.

17 We have not made any attempt to discriminate between unmarried and married women, except that we have investigated every acceptable applicant with minor children to assure ourselves that she had means of having her family taken care of while at work in the factory.

18 We begin to train a woman for her duties immediately after she goes to work. We never add many women to a department at one time, as we have found it impossible for an instructor to give to each of many new employees sufficient attention to obtain satisfactory results. If we take on too many women at once it is necessary for them to wait some time for instruction. In this interval they become discouraged, impressed with the thought that they will never learn, and usually nearly all those who have not been given the undivided attention of the instructor during the early days of their employment, resign, apparently having reached the decision that the work was going to be so difficult that they could never learn how to perform it. But when the new employee can be given the undivided attention of the instructor and can have the operations explained until understood, there has been laid the foundation for a probable permanent employee, and one whose work will in almost every case be satisfactory. We attempt to instruct two women at one time on each machine tool, giving them alternate opportunities to operate the machine tool themselves, but under the immediate and direct supervision of the instructor who is assigned to that particular job.

19 We found early in our experience that we had a smaller percentage of failures when our women employees came from the industrial walks of life, that is, from families in which the husband, brother or father was a mechanic. The women then understood many of the machine operations, particularly if they had a sewing machine at home or were familiar with modern household apparatus.

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If we drew our prospective employees from those walks in life where the men of the families were engaged as bookkeepers, clerks, or on similar work, the women had to receive much more instruction and they were more easily discouraged. And while now we do not limit ourselves to any particular class, we do give the preference to those applicants where the fathers and brothers are working on mechanical operations.

20 We find it difficult to teach women to operate screw machines, but when they learn, their work is as satisfactory as that of men; and on the lighter screw-machine work we are having the remarkable experience of finding their work more productive than

WOMEN OPERATING SCREW MACHINES

that of men. We do find it difficult to teach women how to operate milling machines and we have had many failures, yet we have women operatives on milling machines doing high-grade work as efficiently as it can be done by men. We have found it difficult to teach women to operate lathes, but now have good women lathe operators in our employ. It has never been difficult to teach women to operate light punch presses, and although we have always considered heavy-punch-press work a man's job, we now have women operating heavy punch presses in an entirely satisfactory manner. We have always considered the assembly work on some of our more important operations as being essentially the work of the man who

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had been trained as a mechanic; but we now find that when properly instructed, women can do this work in a way that is entirely satisfactory to us.

21 It has been necessary to more closely supervise and inspect the work turned out by the women than by our regular run of men employees, for few women have any conception of the importance of dimensions, or any judgment as to mechanical strength or requirements. Therefore they work by instruction rather than from any inherent mechanical knowledge. But you can be sure that

TYPE OF CLOTHING WORN BY WOMEN ENGAGED IN SHOPWORK

once a woman employee is taught how to use a gage or learns what constitutes satisfactory work, the good work produced in the afternoon will be exactly the same as that produced in the morning. The judgment which is frequently so disastrous on the part of our men employees will not enter into the work of the woman operative. She will follow instructions absolutely. Therefore it is extremely important for the instructor to go into the minutest detail when he is outlining the work.

22 We have found it very difficult to teach women the difference between a dull and a sharp cutting tool. But all the difficulties mentioned, as well as others, are within the possibilities of

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correction; and there is no inherent reason why the women of this country should not do most of the work in our machine shops, although regulations governing such work must be more carefully stated and followed than when men alone are employed.

23 As a rule, the best results are obtained when the supervision of work is under the direction of men, although as immediate superiors of the women other women can be used to advantage.

WOMEN OPERATING LIGHT MULTI-SPINDLE DRILLS

24 More attention must be paid to the appearance of the manufacturing departments when women are employed, for women are much more susceptible to surroundings than men. In shops where women work, the machines and floors are kept cleaner than in sections where men only work. Women are naturally better housekeepers than men, and when the women understand the need or desire of keeping the shop in good order they assist in maintaining a high standard of appearance where men are often careless and indifferent.

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25 When a woman begins to work in the factory it is of the utmost importance to impress on her the need of great care in the handling of machinery and also to explain that we are going to coöperate with her in keeping her free from accident hazards.

26 Difficulty with the clothing of women engaged in shopwork has been one of the most important problems we have had to solve, since loose sleeves, thin waists, skirts and unprotected hair are not

WOMEN OPERATING LIGHT PUNCH PRESSES. THE WIRE GUARDS HAVE A SMALLER MESH THAN WHEN MEN OPERATE THE MACHINES

safe in a machine shop, and to meet this problem we have encouraged the use of clothing more in keeping with factory conditions.

27 When we originally adopted our plans there was some uncertainty as to whether we should ask our employees to wear the type of clothing shown in the accompanying photographs; and in order to settle the question once for all, the matter was submitted to the workers in a certain department for their own decision. We had had a few minor accidents due to loose sleeves, uncovered hair and loose skirts, and it was evident that in order to protect our workers it would be necessary to adopt some type of clothing which

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would remove that industrial risk. We arranged for a conference with our employees in the department mentioned and left to them the selection of the clothes which they should wear. We explained to them the reason we were increasing the number of women, that it was necessary to have these women to take the places of men, that we intended to employ more and more women in the future, but that we could not forgive ourselves if we permitted their employment to result in accidents which might ruin their usefulness in future years. The conference was a most interesting one and the results were surprising; for of those who attended, 98 per cent voted, after a half-hour's consideration, to adopt the clothes which are illustrated in the cuts that accompany this paper.

28 It was feared that there might be some confusion when the women of the department first appeared in their new clothes. And there was possibly a half-hour in which they did arouse some curiosity and interest. But since that time the factory costume has taken its place among other conventions and now receives no special attention. We have found it advisable to have all the factory women wear the same kind of clothes except the stockkeepers, who are exempt from this regulation if they so desire. Many of them, however, have adopted the regulation costume voluntarily. Of course, we do not ask or want our factory office employees to wear clothes of this type; they are only recommended and used in the factory proper.

29 Machines must be somewhat more carefully safeguarded if women are to operate them than if men were doing the work. In general, safety for women who wear proper shop clothes is provided by the same safeguards as for men, except that with wire guards it is necessary to make the mesh smaller so that the hair cannot get through and to place the guards farther from the moving parts.

30 The segregation of operatives has been given a great deal of attention. Until the present emergency we have made an attempt to separate our women employees from our men. We do now arrange to have our women employees quit their work a few moments earlier than the men so that the women can leave the factory without confusion, but we are making no attempt to separate them from the men in the manufacturing departments. They of necessity work on adjacent machines, for when the man who operates one of a line of machines is called to military duty we cannot move that one machine from its desirable location, but we can train a woman to operate it. Where the number of women in

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a department is relatively small, the desirability of segregation is most evident, and if it were possible we would segregate operations; but it has not been difficult to entirely control the situation by proper supervision, and now that our men are becoming used to women workers, the interruptions and confusion have practically disappeared.

31 It might be well to say that the men have not objected to women working in the machine shops. While we feel sure that there would have been objections raised last year, this year the men are giving the most helpful assistance in the training of women to do the work properly, for all recognize the importance of carrying on the industrial undertakings by women, as men are required for military work.

32 We have found in all classes of factory operations that women are more attentive to their work than men. They are more prompt, observe factory regulations in a better manner and, in general, are neater about their work, but we have not been able to impress them with the importance of being on hand every day. Many seem to feel that it will be perfectly satisfactory to be absent occasionally, particularly if they have any household duties to finish, and for this reason we have been careful to select those women who can be entirely relieved of such responsibilities if they enter our employ. Our record of absences of women is as a rule about 20 per cent greater than among men.

33 I have mentioned changing occupations in the manufacturing departments. We have also carried on a most successful experiment in the employment of women in one of the estimating departments. We have always employed many women secretaries, stenographers and clerks, but until recently have not found it advisable to employ women who were graduates of women's colleges in our commercial estimating departments, there having been a sufficient number of men trained in technical colleges to fill our requirements.

34 The withdrawals for military service, however, have practically exhausted our supply of technical graduates, these young men being the first to take part in military activities. We found ourselves, therefore, without a sufficient force to carry on our work, and recognizing the situation, employed a group of college women, who are taking up the work heretofore carried on by the younger technical graduates. These young women had no technical training. They are, however, well educated and we selected those who had

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specialized in physics, chemistry, or other work of this character when we made our appointments. Then we immediately started an elementary course of instruction. The activity and interest of this group of young women is all that could be desired. They are more anxious to learn than the young men. The majority of them are not only anxious to earn their own living, but are most anxious to do some definite work which will release additional men for military duties. It is as yet too early to make definite statements in regard to what has been accomplished, but the situation is most promising and there is no reason to believe that our experiment will be anything but successful. This change cannot be brought about in a moment, however, — there must be painstaking education and patience with inexperience.

35 We believe it will be necessary to carry on a very systematic campaign before we can educate enough women to do the work that will be required of them if this deplorable war continues. We do know that we must release many more men ultimately. We do know that we must supply more articles of manufacture, even if these men are not available. We know also that women must take the places of men if we are to carry our undertakings to a successful issue.

36 The danger is not that too few women will be employed, but rather that so many may be engaged at one time that they will be given work to do on which they will not have received proper instruction and which will, therefore, be improperly and inefficiently performed. But if the employment is properly safeguarded and the character of the women carefully and intelligently scrutinized, I am sure it will be found that they will give their most undivided assistance in manufacturing work, and that as a result of this assistance they will release for military duty thousands of men who are now employed. If our experience in the future is a repetition of what it has been in the past, then we are going to find these women employees loyal, energetic and efficient, and a group which, if properly instructed and controlled, will solve successfully our present industrial problem.

37 As to the future, who can predict? Will the women we train on the work of men desire to retain their positions? It would be a wise prophet who could give a true answer at this time. But it would appear from our experience with thousands of women who have worked on the lighter machine-shop and assembly operations that these women are always looking forward to the time when

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they can leave their industrial occupations and take care of a home of their own, and I do not believe that there will be any different condition after the war is over. The women who are entering our employ are prompted to do so because they are trying to do their part and because they desire to assist or supplement the family income. And it is probable that the larger number will desire to drop their factory work on the day that their husbands, brothers, or fathers return and are able to do the work for them.

38 There seems, therefore, much to be gained and little to lose through encouraging an educational campaign on the employment of women for the duties of industry which have heretofore been left entirely to men. By reciting our experiences we can quickly arrive at the most efficient method of selection, education and training.

39 We must tell others what we have learned regarding the employment of women, what capabilities they possess, to what kinds of work they are best fitted, what type of women to employ, how to organize the factory to the best advantage, how to train them to increase production, what subdivision of operations is necessary, and so on.

40 We can by publicity encourage the women of one community to follow the example of others. And by raising the plane of factory employment we can avoid the perplexing social distinctions that have been so troublesome in England. And it would be the writer's suggestion that this Society become a clearing house through which we can report and unify our methods and obtain the best results in meeting our present emergency requirements.

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No. 1628

INFLUENCE OF ENVIRONMENT ON THE WOMAN WORKER

By C. B. Lord, St. Louis, Mo.
Member of the Society

PSYCHOLOGY, either accidental or predetermined, is the basis of successful management. Walter Dill Scott says, "The time has come when a man's knowledge of his business, if the larger success is to be won, must embrace a knowledge of the laws that govern the thinking and acting of those who make and sell his products as well as those who buy and consume them."

2 A knowledge of these laws enables us, when making rules, not to forecast with certainty, of course, but to make an inspired guess as to the effect of any cause in advance of its execution, and thus to lessen harmful experiments.

3 The part of this discussion assigned to me mentions environment only, but we must not forget that in this case environment has a direct bearing upon heredity, and that most of our troubles are psychological. When the wise man said that the training of a child began thirty years before its birth, he had in mind the physical well-being of its mother and the moral training of its father, for both of which, as employers, we are largely responsible.

4 As I see my duty, it is to secure maximum efficiency. This includes maximum average output, continuity of attendance and employment, a minimum of mistakes, and the anticipating of future requirements. If this entails analysis of mechanical requirements, a clean factory, and surroundings tending to cheerfulness and begetting modesty, then I am going to do all these things. If securing the desired results necessitated doing the opposite, that would I do. Therefore I want to disclaim any benevolent interest and put the matter on a practical dollars-and-cents basis. I can more readily do this, as it has been my experience that maximum of efficiency is secured by attention to the details just enumerated.

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5 We find that contentment in woman is not induced by allowing her too great liberty of action, but rather in laying down strict rules for her guidance. When she becomes habituated to these rules, she accepts them as logical limitations and is content, provided always that they are just, equitable, and for her ultimate good.

6 Dissatisfaction with surroundings is a prolific cause of discontent. The same building, the same old stairs, the same rough bench and the same work contribute to this — unless the worker be sister to the ox — in mental fatigue. And as these influences are cumulative, a crisis is possible at any time, affecting maybe the individual only, perhaps the group or mass — trifles, perhaps, and yet such slight irritation has caused more murders and started more revolutions than has oppression. And so cheerfulness is an important factor.

7 The temperament of woman makes her acutely sensitive to color. She is influenced longer by the mourning she wears than by the loss of the departed. She also has an intuitive desire to decorate herself, and to be opposed to surroundings that satisfy the average man. This desire, carried too far, is destructive of efficiency, as is also an entire lack of it, but we can at least cater to her innate delicacy to the extent of having neatness and cleanliness. And so in harmony with this idea all machines that are operated by girls are painted with a white, oil-proof enamel, not as a fad, but to promote cheerfulness. Our floors are scrubbed, not impulsively, but regularly. Our toilets are clean, not disinfectantly, but soap-and-water clean. It would seem beneath the dignity of an executive to be responsible for clean toilets, yet it is indicative of his management.

8 Personally, I am tending more and more to the conclusion that the efficiency of men and women lies as much in their mental attitude as in their manual skill. I do not mean by this that contentment makes them skillful. It does not, but if they possess a certain skill, contentment enhances their productive output and lessens their liability to mistake, hence increases their efficiency.

9 Woman is more self-conscious, probably I should say sex-conscious, than man. This is indicated by her inherent fear of men in general, and her equally inherent desire to attract man in particular. In this latter the decorative instinct comes into play and begets clothes consciousness. While it is common to both sexes, it is intensified in woman.

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10 During investigations which I made as to the influence of wages on morality, I came to the conclusion that while there was no general connection between the two, where immorality did exist it was due to a desire, not for better education, or food, or surroundings, but for better clothes either to arouse the envy of her fellow-workers by outdressing them, or to mingle in society beyond one's means.

11 The point of all this is that no woman who is clothes conscious is efficient, and any woman who is either not so well dressed, or is better dressed than her neighbor, is clothes conscious. The obvious answer is uniformity of apparel, but with sufficient latitude to permit the exercise of individual taste. We have found the remedy by furnishing at cost an unfadable blue chambray. I want to emphasize the unfadable, for it is this that makes it successful, and as the waist is the most in evidence, and most abbreviated, we require a uniform waist and apron.

12 The success of the uniform depends upon an absolute enforcement of the rule. It is one of the peculiarities of feminine psychology that women will obey almost any rule, however disagreeable, if it is enforced impartially; but if favoritism is shown trouble immediately results. Having in mind the pleasure women take in showing their clothes, and also that they may want to go shopping on Saturday afternoon, we make it optional with our women employees whether they wear uniform waists or not on Saturday.

13 I mentioned as one of the features of my duties the ensuring of a future supply. Marriages in our plants average nearly two per month where both contracting parties are employees. These marriages are invariably successful because they are the result of observation, one of the other, under the most commonplace conditions, and not the result of proximity of one to the other, each in his best clothes and on his good behavior. The uniform waist is a big factor in this; it gives girls a clean-cut, neat appearance, with only the advantages nature gave them.

14 In some factories girls are wearing overalls, but I think it will be found that they, or the ones responsible for the decision, were rather masculine. In my estimation, this masculine tendency accounts for much of the feminist agitation of the present day; it also accounts for the increased efficiency of women, as the reasoning and point of view are more masculine. This type also lacks acute sex consciousness and looks a man straight in the eye, but unfortunately it also has the masculine moral aggressiveness, or I might say

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a lack of feminine retirement, and constitutes a dangerous element in the shop.

15 In an article which I recently wrote for *Industrial Management*, I described our method of combating this condition, and do not wish to reiterate, but I am reminded of Katherine Blackford's remark to me in this connection, that a man's passion is the dynamo that determines his ability; but, of course, she did not mean that he has to violate the social code just to prove it.

16 According to Blackford, man may be classified by eight cardinal attributes, but for practical purposes woman may be classified as masculine, feminine, short- or long-fingered, phlegmatic or nervous, usually interchangeable terms, and sometimes blonde or brunette, for there is considerable wisdom in the maxim, "Send a blonde salesman to secure customers, a brunette to keep them."

17 In considering comfort and contentment we must bear in mind that fatigue may be caused by position, by improper form or height of seat, improper foot rests, or lack of them, awkward fixtures, left-handed girls on right-handed machines and other minor causes. These are all remediable troubles, but unless adjusted they cause girls to quit, and foremen to discharge them. It should not be forgotten that as the poor workman quarrels with his tools, so does the poor executive complain of the labor material at hand, and tells what he might do were it better.

18 I do not know whether or not the question of pay comes under the head of environment, but as much of it goes for clothes, perhaps it may be classed as such. It is a perplexing problem and one which must be settled locally, depending, as in other things, upon supply and demand. A woman is not so strong as a man, but is more dextrous; she has not the reasoning power of a man, but has a quicker mind. Where either of these attributes add to her ability, she should reap the advantage. Where piece rates are set, they should apply equally to both sexes, but when I am asked should she receive equal hourly compensation with a man, I must answer no, but she should receive as much as, or more, than a good-sized boy.

19 I will conclude as I began, by quoting Scott, who says, "Psychology is, in respect to certain data, merely common sense — the wisdom of experience, analyzed, codified and formulated."

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DISCUSSION

J. N. BETHEL,[1] said that his company had successfully employed 32 women in their surface-grinding department, and that four of the machines which they operated had run for several months on work that called for absolute figures with an allowable error of less than 0.0001 in.

About twelve girls worked on milling machines. They were not mechanically qualified to set up their machines, but when given good rigging hands and set-up men and closely supervised and carefully instructed, they did very well indeed.

Thus far girls had not been employed on screw machines, but an alternative department was being installed to teach them how to operate screw machines, lathes, milling machines and cylindrical grinders, and he was certain that with the aid of this department, girls would help solve the labor difficulties.

JOHN W. HIGGINS reported that the Worcester Pressed Steel Company had been exceedingly successful and pleased with their experiment in using girls in the manufacture of large cartridge cases, helmets, etc., both on screw-machine work and press work, and especially in inspecting and gaging. They were deft and uniformly more successful than men in these operations. Classes had been planned in the trade schools for the preliminary instruction of girls who had not worked in mills, in operations of inspection, gaging and assembling, and also to familiarize them with machine-shop methods and practice, especially with a view to their protecting themselves against accidents by teaching them the dangerous points of a machine and also how they could conserve their strength.

FRANK E. BLAKE [2] stated that the Remington Arms Union Metallic Cartridge Company had employed women for about forty years. In their new rifle plant, originally organized and equipped for men exclusively, 1300 girls and women had been very successfully employed in milling, drilling, polishing, filing, inspecting, and all of the operations in the shop not requiring a man's strength. A uniform had been adopted consisting of a net cap, which provided the ventilation that a more closely woven cap would not give, and an apron of an approved design. He felt that the girls in the shops would stay

[1] Taft-Pierce Mfg. Co., Woonsocket, R. I.

[2] Remington Arms Union Metallic Cartridge Co., Bridgeport, Conn.

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there after the war, for they were doing good work, and work that was satisfactory to the management.

L. W. WALLACE said that women had been employed by the Diamond Chain Manufacturing Company for 25 or 30 years, and that 30 per cent, or 300, of the factory force were women. They were used successfully on punch presses, light and heavy assembling machines, automatic machinery of all sorts, drill presses, etc., and on assorting, gage-inspection and assembly work. Women in the engineering office did drafting work and two university graduates had charge of the bonus and cost departments. A woman called "Director of Mutual Service" looked after the welfare of the women, their wage increases, discipline, discharges and disputes. Men and women worked together, and got their pay from the same window. The general plane of the factory had been very much raised, and in consequence they had no trouble in attracting to the factory a high type of young womanhood.

MRS. HARRY E. HEUSTIS[1] explained how the women of Canada had volunteered as munition workers, supplementing men for war service. They had gone in as machine operators on drills and other machines. Three women had become experts in rifling and their output in quality and quantity was as high as that of any male expert.

KATE GLEASON emphasized the fact that the best class of women were becoming attracted to the work in the skilled industries. In years past they had been used on automatic machinery, which deadened their minds. She cited the case of a woman in Berlin, employed at ordinary work in the Deutschen Waffen Fabrik, who, when the man at the head of her department had answered the call to arms, and she had been given his place, rejoiced in the pride and power of a real job. She also spoke of the work accomplished by a woman in charge of one of the manufacturing departments of a Rochester shoe factory, by means of which team work in production was brought about so successfully that it was found possible to cut the price of shoes in half.

MAJOR FRANK B. GILBRETH, referring to the question of unnecessary fatigue, said that it should not be confused with necessary fatigue. A fatigue survey should be made in each plant. This would

[1] Superintendent of Women, Ross Rifle Works, Quebec, Que.

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bring out the fact, for example, that women used the wrong kind of chairs. Nearly all women insisted on trying on their shoes before they wore them, but few in this country, certainly not one per cent, had had chairs assigned to them, with their names or numbers on them, and yet the necessity for that was perfectly obvious. The idea of assorting people by the top of the head from the floor, when it was the elbow that determined their length from a sitting or standing position was absurd.

Major Gilbreth said that he agreed with Professor Kimball, who had stated the day before that mechanical engineering consisted of almost everything in the world. He then continued, "I also agree with him on the psychology of management, and yet how little we act from a psychological standpoint, having the employees and employers get in the habit of meeting on some subject, coming together during the period of lockouts and strikes. If they would take this subject of the elimination of unnecessary fatigue as one typical case that they have no scrap about, and get in the habit of agreeing, it would be of great benefit."

A. W. MARSHALL related an experience with two damage cases against employers on behalf of girls who had had their scalps torn off on account of working near moving machinery and were mutilated for life. It was therefore of extreme importance that the women's hair be protected, either by caps, or by having the machinery amply protected. Both of the injuries cited had been due to the fact that the shafts on which the hair was caught were charged with frictional electricity, which attracted the hair to them.

E. J. POOLE took up several questions concerning the employment of women in the steel industry. In the matter of lifting, it had been found, he said, that up to a certain point women were just as efficient as men. As to the question of mixing nationalities, he believed that this should be done in order to avoid trouble.

On the question of wages, he had followed the system that has been very successful in England, namely, two-thirds of the wages of the men who are on that particular job. When the women became proficient they received the full wages of the men. On piece work they were given the same piece-work rate as men.

As to close work, in grinding, for example, it had been his experience that women did a great deal better work than the men they had formerly employed on that class of grinding.

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GEORGE F. BLESSING spoke of the research work done in Swarthmore College, a coeducational institution. "Fatigue-elimination day" was observed by having the juniors in drawing and kinematics design fatigue-eliminating devices that might apply to their own work, such as study boards, desk helps, etc. In the shop two of Major Gilbreth's chairs were built and demonstrated. An exhibition of devices obtainable in the market was also held in the engineering laboratory. The members of Professor Blessing's class in industrial relations were required to submit written reports of working conditions found wrong in the college.

FREDERICK R. HUTTON recalled the visit of the Society to the factory of the National Cash Register Company, Dayton, where the very best quality of women workers was secured by the simple means of allowing the women to leave the plant five minutes earlier than the men so that they might reach the trolley cars a little ahead of the rush.

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No. 1629

THE ENGINEER, THE CRIPPLE AND THE NEW EDUCATION

By Frank B. Gilbreth, Providence, R. I.
Member of the Society
and
L. M. Gilbreth, Providence, R. I.
Non-Member

This paper is a progress report and states definitely the work that the engineer should do to help the cripple to be independent of all charity. It states how the cripple can be enabled to compete successfully with normal workers in the trades at the present time. It calls attention to the fact that the cripple after receiving intensive education by means of micromotion study is able to earn more than normal workers who have not received such education.

The war has made an upheaval in many methods, particularly those of education. After the war the intensive methods now used in our emergency will be used permanently. These methods are not transitory. They will remain because they are more efficient.

The intensive education in motion study of the one best way to do work, now being done for the cripple, is the model for all the intensive training of the nation's workers after peace comes — that they may become more efficient and more productive and suffer less fatigue. The military cripple will thus have served his country doubly.

THE purpose of this paper is to report progress in the solution of the problem of training the crippled soldier. At the present stage of this work, we are able to formulate certain conclusions that have a bearing upon the activities of this Society and upon the part that the Engineer should take in the Crippled Soldier work.

2 These conclusions are as follows:

a The Crippled Soldier problem is practically identical to the problem of the cripple in general

b Its solution lies in a new type of education

c This education is destined to be the education of the future

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d It is based on
(1) Finding the ONE BEST WAY TO DO WORK
(2) Adequate assignment to work, i.e., intensive vocational guidance

e The engineer is best fitted to determine the one best way, to formulate it into methods, and to supply necessary devices and mechanical appliances.

3 All cripples, no matter what the cause of the crippling, require a training that will be mentally satisfying and physically beneficial. This training must be such as will enable them to become productive members of the community, and to remain on the world's payroll. This implies either competing with non-crippled workers in occupations open to all, or setting aside certain work for crippled workers exclusively, or both. It implies discovering and making available such opportunities for crippled workers, discovering which cripple is best fitted to utilize the opportunity, and training him to make the best possible use of it. It also implies not only opportunities for individual development, but such social opportunities as will enable the cripple to fit back into the ordinary social life with the greatest ease and the largest amount of durable satisfaction.

4 Those crippled in war furnish a small percentage of the total crippled as compared with those crippled from other causes, such as disease and accidents, especially in the industries. This is true even in Canada, which has furnished such a remarkable quota of fighting men in comparison with the total number of her population.

5 The solution of the crippled-soldier problem as outlined above consists of a type of education that is *new* in that it eliminates the greatest amount of waste possible in the educational process. It teaches *the one best way* at the outset, instead of following the old practice of "learn every way," with the vague hope of arriving at efficiency as an outcome. It enables the learner to arrive at a desired outcome with the greatest amount of speed and the least amount of effort, and with the largest return in efficiency and the resulting satisfaction.

6 Because of these qualities, this new education is bound to be used in the future not only in the reëducation of cripples in what is to be their new life work, but in education in general. Just as the Montessori method of teaching children, which originated in an effort to discover the best method of training subnormals, proved so successful in that field and demonstrated such underlying principles of general applicability that it now occupies an important place in the

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training of normal and supernormal children, so this new method of education, discovered as a result of synthesizing measurements of champion workers in our *quest of the one best way to do work*, is spreading through the general interest in reëducating military cripples to the reëducation of all cripples, into the manual-training schools, corporation schools and the general educational fields.

7 The new education has two parts: first, discovering the one best way to do work, and second, testing the individual and placing him at the demonstrated most appropriate work. By "work" we mean activity of any kind, whether physical or mental, for the investigations and the resulting methods are being made and applied in mental as well as physical fields of activity, as a result of our findings based on micromotion and cyclegraph records which prove that the laws of habit formation apply equally well to mental and motion work.

8 There should be little argument as to the desirability of finding the one best way to do anything, regardless of whether it is immediately learned, taught, or habitually practised. There has been considerable discussion as to the possibility of there being any one best way, and also as to the possibility of finding it, if it does exist. The important thing is that there certainly is one best *available* way. There is no question of this, since it has been demonstrated both in theory and in practice. This way seldom if ever exists in the consecutive motion-cycle units of any one individual, though their units may be in general use, and many will undoubtedly be used by every expert in the activity.

9 Of the matter of tests and assignment and placement at most appropriate work, we need only say here that the discovery of the one best way of doing the work and the consequent standardization of the best methods and equipment will allow of tests that are more adequate. For this reason, if we can test the proposed worker with the method and device that it is planned he shall use, we shall have less variables in our testing process than is the case at present, and we shall have less difficulty in the evaluation of the tests, and less necessary transfer.

10 The engineer is the natural person to whom the world now looks to find *the one best way*. This one best way is based on accurate measurement, — not guesswork, personal opinion, bias, or the vote of a majority of a committee who have not measured. The engineer's training in measurement fits him specially for doing the requisite work.

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11 To recapitulate, the *extent* of the cripple problem is, then, practically unlimited. When we come to consider the subject closely we see that every one of us is in some degree a cripple, either through being actually maimed or through having some power or faculty which has not been developed or used to its fullest extent. The degree of crippling extends from the worker who, through some accident, has lost his eyesight, his hearing, and the use of his legs, arms and hands except for the use of one finger, — and by the way this is no imaginary illustration, as we have lately received a skillfully woven bag made by such a cripple maimed through a mining accident, — to a man who is dependent upon glasses for reading. From an efficiency standpoint a policeman with corns on the soles of his feet or a golfer with the gout in his toe is more of a cripple during his working hours than a legless man while operating on a typewriter. We can, then, think of every member of the community as having been a cripple, as being a cripple, or as a potential cripple. Conversely, we can think of a badly mutilated man as not being a cripple during the period that he is at that work *the performance of which is not affected by the mutilation.*

12 As to the *nature* of the problem of the cripple, it is a problem of education, as has been said. *With the present state of the art of teaching it is largely a problem of reëducation*, since most of us, non-crippled as well as crippled, have received the wrong type of education and must be reëducated even in the fundamentals. As an example of the inefficient method of education, consider the practice of having foreign languages taught exclusively by teachers speaking dialects or worse instead of by supplementing the best available teaching by talking-machine records of the experts in pronunciation. As education becomes more scientific the problems of reëducation will become simplified, and the process will become shortened.

13 As to the natural solvers of the problem of the crippled soldier, these are, as before stated, the engineers, but only if the engineers will bring to the task the scientific attitude. As a profession we have been too apt to be satisfied with half-way methods and half-way devices. We boast of the advance in engineering science, especially of the advances in the science of management, which have to date been, with few exceptions, the work of engineers, yet general knowledge and use of instruments of precision, even when such are available, are lamentably lacking. As a specific example of this we may cite the use of the stop watch by experienced and earnest investigators in the field of time study. If the engineer, knowing as he must that it is an insurmountable barrier to obtaining *the best method*, or even know-

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ledge of times that are transferable to others, is to discover *the one best way to do work* he must use the best methods and instruments extant, and he must apply these with unremitting accuracy, persistence and patience. *The one best way* consists of elements of motions accurately timed and recorded, and synthesized into the best available method of activity.

14 If the engineers are, as a profession, ever to take the place that they should take in this work they must start *now* to coöperate with those working in other phases of the subject. The various aspects of the problem are being assigned to those best able to handle them. For example, the task of making surveys as to what should be and is being done and of the opportunities open to cripples can well be undertaken by cities, towns and other civic organizations. This is being done, notably in Chicago, where we are assisting in the excellent work now under way under the leadership of Mr. Pike, Mr. Petterson and others. The matter of furnishing money for the investigations and for the work itself is being excellently attended to by the Red Cross, as, for example, through the Red Cross Institute, New York City, with which we are coöperating, which has sent Dr. Edward Devine abroad for personal investigation and service in the field. There is also the work of Mr. McMurtrie, Acting Director of this Institute, who is collecting a bibliography on the subject of cripples. The matter of investigating the extent of the crippling and of providing the surgical and medical attention necessary is being admirably handled under the able leadership of the Surgeon-General and other Government representatives, already famous in the medical and surgical profession, in Washington. Too much credit cannot be given to Dr. Franklin Martin and Surgeon-General Gorgas for the progress that they have made in this great work in the short time since the day after the declaration of war, when they individually honored one of the writers by giving him an interview for the purpose of outlining possible work along these lines. Since that time he has been honored by being appointed on Dr. Martin's committee reporting to the Council of Defense, and is now also coöperating with Col. Owen and other famous doctors in the Surgeon-General's department.

15 The psychologists have appointed committees to investigate all branches of the subject that come within their field. The psychotherapists are working on their aspect of the problem, and Mr. George Edward Barton of the Consolation House at Clifton Springs, Past-President of the National Society for the Promotion of Occupational Therapy, has spent years in theoretical and practical work concerning

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the convalescence period and is contributing his experience and energies toward helping this cause. Educators are considering not only the training of the necessary teachers but the training of the cripples themselves, notably Prof. Frank E. Sanborn, of Ohio State University, and Prof. Wm. S. Ayars, of Nova Scotia Technical College, an American engaged for years in teaching in Canada, both of whom are members of this Society.

16 A Government bureau for collecting and conserving all these data will come naturally as a development of the activity in other fields and of the present activity of various Government departments along various lines. This bureau should contain a museum that would include among its exhibits models of artificial limbs and appliances for cripples.[1] This, supplemented by state and municipal museums along similar lines would bring first-hand knowledge to the cripple, who too often buys the first artificial limb that he sees, and usually averages three or four purchases before he gets the one best suited to him.

17 Such a national museum should also contain fatigue-eliminating devices, which would enable all workers to become more productive with less accompanying fatigue. The writers first called the attention of this Society to this need in 1910, feeling that fatigue study, like accident prevention, is a function of the engineer. We have, since 1913, started several small museums of devices for eliminating unnecessary fatigue, hoping that the movement would spread, and in the winter of 1915 tried to get the National Museum at Washington to start such a department, but apparently were not able to arouse much interest, though we were asked and thanked for a collection of wire models of motions. Recently Col. Owen became interested, and now a definite start has been made.

18 The great need for fatigue elimination for the crippled soldier will undoubtedly lead to interest in the subject in this country as it has in England, for until recently we have had much more encouragement in our campaign for fatigue study from Englishmen than from our own countrymen. Mr. James F. Butterworth, ever ready to disseminate information relating to managerial economics, was the first to bring the matter to the attention of the British public. Prof. A. F. Stanley Kent incorporated his investigations of fatigue of munitions workers into Reports, written by order of the King, since reprinted by this Government and obtainable at Washington. Prof. Henry J. Spooner wrote a series of articles on Industrial Fatigue in its Relation to Maxi-

[1] See Fatigue Study, Sturgis & Walton Co., New York.

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mum Output for *Co-Partnership* (London), since issued as a booklet, which should be in the hands of every engineer and employer, and should also be reprinted by our Government and put on sale by the Superintendent of Documents.

19 The data for such reports and articles come from investigations of present conditions, and realization of their significance. If the present chairs and work benches now to be found in all parts of this country as well as abroad were collected and put beside such efficient devices as the Barney chair and foot rest, and the Marshall traveling chair they would look as out of place and cruel as do the devices of torture of the medieval period. Observing this, and with the cripple in mind, it will be noted that the principles underlying the adapting of chairs and foot rests to the industrial worker's measurements and to the needs of the cripple are identical. If this had been realized more generally sooner, more people would have taken up fatigue study and the devising of chairs, foot rests and benches to meet the national after-the-war need for more efficient working conditions for cripple and non-cripple alike.

20 This profession as a whole has not given the full benefits of its education, training and ingenuity to the industrial cripples of the past. The more we investigate the problem of the cripple the more we marvel at their patience and the fortitude with which their calamities have been met and endured. They have made so few demands. They have been so pitifully eager to coöperate in this new work. They are, throughout the entire country, for the first time seeing the opportunity to do constructive work for their fellows, not only by showing what the maimed and handicapped can do but by acting as examples of cheerfulness and continuity of purpose for all to follow. They are seizing this chance to do their bit for the war and for their country, and have shown such intelligent coöperation that we are led to agree with Mr. Fred J. Miller, Past Vice-President of this Society, that a man who has lost a limb becomes thereafter more active both physically and mentally.

21 Now the needs of our industrial cripples are supplemented by the more pressing need of the crippled soldiers. The crippled soldier is at a disadvantage, as compared with the industrial cripple, in that he is often at a distance from aid of various kinds at the time that the crippling takes place, and thus misses the chance for the early reëducation that is desirable and necessary. Second, in that through mistaken kindness he is not taught work of any kind during his convalescence and during the period immediately after his return home;

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in fact, he is often encouraged by misguided friends to remain idle until the possibility of teaching the maimed member and the mind that has stopped learning has decreased, and reëducation becomes more difficult, if not actually impossible. Third, through the terrible physical and mental anguish that often precedes as well as follows the crippling.

22 The crippled soldier has the advantage over the industrial cripple in that he is the object of great interest and patriotic sympathy, and therefore a member of the community to be courted rather than shunned; in that he suffers in the limelight, and therefore is practically assured of assistance as soon as the world is convinced as to what he needs; in that he will have, if he has not now, expert training at his disposal; in that he has the consolation of fame and of having done something worth while, even though he had to pay the penalty of being crippled for having done it.

23 For these reasons it is advisable that the engineer turn his attention immediately to the problem of the crippled soldier, supplying the new education in the form of reëducation for this soldier, with the assurance that when the methods and devices have been supplied the industrial and other cripples will benefit exactly as will the crippled soldier.

24 We have already brought out, in papers on progress in crippled-soldier work, the various needs that must be met.[1] One is the need of adapting methods and devices to the cripple, and another the need of adapting the cripple to existing methods and devices. The engineer has a part in meeting both these needs, that is,

a In inventing or adapting detached devices that will make it possible for cripples to do various kinds of work, such as various devices furnished us by the makers of the Remington, Monarch and Smith Premier typewriters, that

[1] Motion Study for the Crippled Soldier, N. Y. Local Section A.S.M.E., October 12, 1915.

Motion Study for Crippled Soldiers, American Association for the Advancement of Science, December 1915.

Measurement of the Human Factor in Industry, National Conference of the Western Efficiency Society, May 1917.

The Conservation of the World's Teeth, a New Occupation for the Crippled Soldier, Consolation House Conference, March 1917. Reprinted in The Trained Nurse and Hospital Review.

How to Put the Crippled Soldier on the Payroll, a paper delivered before the Economic Psychology Association, New York, Jan. 26, 1917. Reprinted in The Trained Nurse and Hospital Review.

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enabled a one-eyed, legless, one-armed and one-fingered typist to write many more short letters in a given time than can the unmaimed champion typist of the world

b In providing artificial limbs to replace those missing. Particular attention is called to the possibilities of inventing countless designs of articulated limbs controlled by systematized use of the trunk muscles controlling the joints of the limbs by means of wires and springs for replacing other muscles and tendons

c In inventing or adapting devices that may be attached to the cripple himself, not to replace missing limbs, but in effect to supply new ones, i.e., additional limbs that will enable him to use existing equipment and thus accomplish work.

25 Artificial limbs may therefore be supplemented or supplanted by what we have called "supplementary limbs"; for examples, (1) a ring or loop attached to the suspenders or belt for assisting a one-armed man to handle a shovel, as suggested and used practically by Dean Cullamore, of Delaware University; (2) yokes, special belts and grasping devices operated by pressure of the body against the work bench; (3) "the third thumb" for holding a magnifying glass.

26 Undoubtedly for all-around and general purposes it would seem to many people presumptuous to attempt to improve much upon nature in the question of the design of the human being. There is a resemblance here to our educational systems. Our educational systems are extremely good in many cases for all-around purposes but they can be easily improved upon by any one who knows exactly what is needed for a special case. We therefore urge all who undertake this work of specially fitting the cripple to perform an activity not to hesitate to "improve on nature" at any time. This new viewpoint will help to handle many difficult cases. We hope soon to present a paper showing in detail practice of putting an extra number of limbs at the disposal of the unmaimed worker, a development of this work for cripples.

27 We have been much assisted in adapting both devices and cripples by the use of our Simultaneous Cycle Motion Chart.[1] Through the elements there listed, such as "search," "find," "select," "grasp" and "transport," we have been enabled to invent or suggest, in highly repetitive work, some contrivances that are creating a new era in efficiency, as can be easily realized when the comparative

[1] See Applied Motion Study, Sturgis & Walton Co., New York.

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simultaneous cycle motion charts before and after the investigation are studied. It is but necessary to call attention to the facts that all "grasping" is not done by the hand; that "positioning" may even be a function of the mouth; that the ordinary workman's apron with its many pockets may be used to relieve working members of the body, and that "inspection" for quantity and quality is by no means always a function of the eyes. There is an opportunity in "the device to handle the device" that will satisfy the yearnings of the most ambitious mechanical and inventive mind, a field almost without end that will eventually make the new era in industry date from the sacrifices of this war. The accompanying pictures show some of the devices and methods already in use, and are valuable simply as suggestions as to what can be done along these lines.

28 We could supplement this plea to the engineering profession to enter into this work as a professional duty, i.e., as service, by an appeal to your sympathies that would bring you into the work with a rush. No one who has not seen with his own eyes the pitiful condition of those who come out of the trenches dazed and forlorn, worse off mentally than physically because of shattered nerves, anxious as to the future, and with a feeling of general unfitness to "fit back" into every-day activity, can realize the pressing need for reëducation and for placement. Next to seeing all this is the reading of the wonderful books of the genius Amar, — Le Moteur Humaine and Organization Physiologique du Travail, — and the study of the illustrations, — actual photographs of workers equipped with his marvelous articulated limbs, — and accounts of the training being furnished in France, at the hospitals and in the reëducation schools, through the work of Amar and those coöperating with him.[1] Add to these the reading of other books, and better yet of personal letters from those in England or Canada who have seen or worked with the cripples who returned before reëducation was definitely attempted, and who, because of lack of immediate training, slipped into idleness and worse. The importance of habits of work must always be kept in mind.[2] This fact has been emphasized by Past-President Hartness in the first two chapters of The Human Factor in Works Management, and by Mr. Henry L. Gantt, Past Vice-President, in various papers read before this Society and in Chapter VIII of Work, Wages and Profits. It is this need for conserving or forming right habits of work that makes immediate action imperative.

[1] To Prepare Soldier Cripples for Industry, The Iron Age, Oct. 25, 1917.

[2] See The Psychology of Management, Sturgis & Walton Co., New York.

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29 For Humanity's sake, for our own sake we, as a profession, must go into this crippled-soldier work. There has been much talk of late years of "the human element," and of the engineer's neglect of consideration of it. The engineer is certainly doing his bit in the war work with material things. This crippled-soldier work is the human-element side.

30 For those who have hungered for religious opportunities, here is the chance. For those who are preaching "Good will on earth," "Love your neighbor," and "As ye would that men should do to you, do ye also to them likewise," here is the big opportunity, and it is at hand, — on every hand. The chance to help our fellowman, — the military cripple, the non-military cripple, in fact all of the nation's workers. The chance to push forward the new learning, the method of attack for obtaining the one best way. The greatest patriotic opportunity to make the entire nation more prosperous!

31 Let us take the three phrases, — the Engineer, the Cripple, the New Education, — and by our activity in the Crippled Soldier work relate these three so closely with one another that through the engineer's participation in the new education the cripple may be transformed from a "discard" to a "champion," who has won personal success in spite of a handicap, and who has used his individual variation from normal to foster the national movement of better methods of education.

DISCUSSION [1]

W. O. OWEN [2] wrote that the new education would be used not only for the training of the cripple, but for the training of the more active man; and the latter would be taught to do his work in a better and more economical way, so that the fatigue of labor would be materially lessened. He felt, however, that the medical man was better fitted than the engineer to determine the "one best way" and to formulate it into methods. The engineer had tried his hand at Panama some years before and failed, and he rather suspected that the engineer would have failed this time at Panama had it not been for a medical man's coming to his assistance.

[1] A more complete account of this discussion, which is here published in abstracted form, will be found in THE JOURNAL for January 1918.

[2] Colonel, Medical Corps, U. S. A.; Curator, Army Medical Museum.

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GEORGE EDWARD BARTON [1] wrote that in his work he was endeavoring to combine the engineer and the cripple by reëducation so that, by making a virtue of necessity, not only was the cripple assisted to health and remunerative labor, but this inevitably became a part of the work of the engineer and not of the doctor. To illustrate, he considered the case of a man who as a result of shock had a spasmodic movement of his arm, which analysis showed to be an irregular, intermittent, horizontal motion. The problem, therefore, was to adapt this motion to the therapeutic advantage of the patient, resulting in some useful product; or to transform it into some other motion which could be so used.

W. S. AYARS wrote that the fact must not be overlooked in the problem of reëducation that the raw material to be worked with was human. The task was not to select and train men for certain jobs so much as to select jobs for certain men and then to train the men and modify the jobs so as to make them fit mutually. In the scientific selection and employment of men it was admitted that one of the strongest points in favor of assigning a man to his job was the man's natural bent toward a certain class of work. Reëducation, as he understood it, was the intensive training given to men whose wounds or disabilities were such that they could no longer earn a living at the occupations they had before enlisting.

Professor Ayars went on to describe the reëducation work done in Nova Scotia for men on their return from Europe. First, in the convalescent hospitals, classes were organized in such work as boot and shoe repairing, automobile repairing and driving, novelty and jewelry work, etc., in addition to English branches and practical mathematics. This sort of work was vocational training.

The Nova Scotia Technical College had planned courses in drafting, garage or automobile mechanics, machine-tool operation, electrical wiring and steam-engine operation. These were intended for men of good common-school education, and for others who could get enough of elementary mathematics in the vocational training classes before taking up reëducation. For men of mechanical taste, but not enough elementary education for any of the above courses, there was a course in boot and shoe making.

Men desiring to take up certain other courses were placed in existing schools or commercial establishments where they could

[1] Director, Consolation House (vocational school for convalescents), Clifton Springs, N. Y.

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learn what they required. A course in janitor work contemplated for such men included the care and operation of boilers and heating systems, a little elementary arithmetic and English, and repairs to wiring, steam pipes and plumbing.

One of the many difficulties encountered in this work was the fact that the men could not be handled in anything like groups or classes. The work was practically tutorial: each man was a unit.

An important point to be considered was the necessity for getting these men started *promptly*. It might be argued that a few specimen cases could be intensively motion-studied and the data applied to all similar cases. But when the number of different possible injuries was considered, and the number of different possible personalities, and the number of different possible trades, jobs, or subdivisions thereof, then the number of permutations and combinations would startle the most hardened mathematician that ever lived, and the task of properly fitting the men to the jobs would require a small army of highly paid experts.

The work with the crippled soldier was very inspiring and congenial. The men were alert, cheerful and responsive; absolutely square and honest in their work, and with the unconscious courtesy and respectfulness bred into them by military discipline. A great many of them, to paraphrase from one of the author's other papers, would bless the day they were wounded, for already the college had placed men who had finished their courses in far better-paid jobs than they held before enlisting, or would have held at present had they never enlisted.

FRANK E. SANBORN was of the opinion that the work with the crippled soldiers should be begun while they were still in the hospital, and as early as their nervous condition would allow. There was nothing better to inspire these men and cheer them up than to have brought to their attention those things which other cripples had done. These could be illustrated by moving pictures and explained by talks. Information should also be given about schools for their reëducation for some occupation. When the men were able to begin their reëducation, what was more natural than to teach them the very best way of doing the work, a way that could be shown to be the best by means of measurements, scientifically obtained — measurements of motion, time, quality and quantity of output and fatigue?

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A. L. CURADO [1] wrote of the willow-furniture industry as affording a remunerative occupation for the cripple. In picking out an industry for a cripple, he said, four things had always to be considered: (1) Could the work be done by a cripple? (2) Was there an economic value to the work? (3) Could the cripple compete with a non-cripple in the work? and (4) Were competent teachers available?

DR. W. R. DUNTON, JR.,[2] thought that the subject of prosthetic appliances was one in which the engineer should coöperate with the surgeon. The latter's knowledge of mechanics, or even physics, was usually not so extensive that an engineer could not give him much aid. A convalescent from pneumonia, a heart case, or a neurasthenic was undoubtedly a cripple in the sense used by Major Gilbreth. Many such cases might be capable of a half-day's work or a half-hour's work four or five times a day. Two such men could make one day on a machine, so that the latter would not be idle.

DR. H. E. HOSLEY [3] thought that from a psychological viewpoint the phrase "disabled soldier" would be preferable to "crippled soldier" as the latter implied entire loss of function, whereas the former suggested the loss of certain parts that functioned but were not of necessity incapacitated or incompetent. Otherwise the author had combined his philosophy and his psychology admirably. He had understood the importance of satisfying the mental as well as the physical benefit. It was one of the greatest satisfactions to the human that he could feel, though disabled, that there were ways by which he could remain on the payroll of the world.

WILLARD E. HOTCHKISS [4] felt that the phrase "the one best way" should have both a time and a subject-matter limitation, for the reason that the method which appeared to be the "one best way" of doing a thing today might not appear so tomorrow, as a new invention in a field apparently quite remote from the one in which a particular process had been developed might entirely change the relevancy and effectiveness of that process.

[1] Manager, Massachusetts Commission for the Blind, Broom and Willow Shop, Cambridge, Mass.

[2] President, Maryland Society for the Promotion of Occupational Therapy, Baltimore, Md.

[3] Phoenix Building, Springfield, Mass.

[4] Professor, University of Minnesota.

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EDWARD CASSIDY,[1] who had been blind for a number of years, wrote that he had been able, nevertheless, to transfer some of his technical knowledge and experience to the blind in Massachusetts, and from his connections with them he realized the ever-growing need of the knowledge of the active-sighted man or woman. These people could be of help in securing for the blind a great many positions in manufacturing plants which they could fill successfully if it were not for the prohibitions in the employers' liability act. The time was not far distant, due to the ever-increasing number of blind persons when business men would be forced to recognize their capabilities and to secure for them self-supporting work.

J. B. MINER[2] called attention to the fact that Major Gilbreth's paper and his basic contribution to motion study suggested three ways in which the science of human behavior came in touch with this important movement. These were the study of fatigue, the study of the learning process and the selection of men for particular jobs. Methods for selecting salesmen which had been worked out at the Carnegie Institute of Technology had proved to be not perfect, but enough better than those previously used to cause them to be adapted to the purpose of selecting officers for the National Army.

Groups of cripples afforded a rare opportunity for experiments under controlled conditions which were so difficult to provide in normal industrial life. The importance of this strategic chance to study selection and learning problems under standardized conditions had been taken advantage of at Carnegie Institute in the opening of a school for training wireless operators for the army. In helping to improve the selection and training of wireless operators, there would be an opening for certain types of cripples which should place them in line for skilled work after the war.

JOHN YOUNGER wrote that one great result of the work of Major Gilbreth and his colleagues would be that the cripple would no longer be relegated as an outcast; for just as there was no stigma attached to the manufacturer who was out of date with his deficient machine tools, so there should be no stigma attached to the man with deficient limbs.

Each engineer and designer should investigate his own particular

[1] Blind Welfare Union, Inc., Boston, Mass.

[2] Professor of Applied Psychology, Carnegie Institute of Technology, Pittsburgh, Pa.

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work and see what he could do in his sphere to adapt his machine to the uses of cripples. In this way a vast amount of information could be made available which would be of tremendous value to our industries and our war-time cripples.

EUGENE R. PIKE [1] related some of the experiences of the city of Chicago in its endeavor to reëducate its crippled citizens. During an investigation which was made, one large industrial plant was found where the records or the company's surgeon showed that during a period of 30 years' operation one out of every seven or eight of the employees received an injury requiring surgical attention. As this plant was modernly equipped in regard to safety appliances, it might be realized what this question meant to the industrial plant of average equipment and the country as a whole.

The Board of Education of Chicago had already under consideration a plan submitted by the Comptroller's Department that contemplated the use of technical schools for the scientific analysis and reëducation of crippled persons so as to fit them to do work for which they were best suited, mentally and physically, thereby still retaining for the use of the country the brains and ambitions that were not injured and for which there was an ever-increasing demand in industry.

CALVIN W. RICE outlined the work the French Government had done in the reclamation of war cripples. Those capable of reëdution were men who, in spite of their crippled state, still represented a social value close to normal, and it was estimated that about 80 per cent of the wounded belonged to this class. The idea was to give men wounded in the defense of their country means to continue a useful existence and take part in the industrial life of the nation, and it was believed that this effort would be materially helped out by the great scarcity of labor throughout the world after the war.

C. N. UNDERWOOD gave particulars of the remarkable case of an employee of the Remington Typewriter Works, who, due to sciatica and inflammatory rheumatism, was a cripple from bust to knees, with the exception of his arms. Mr. Underwood had projected on the screen motion pictures showing the man at his work as an inspector of typewriters, and also dexterously performing some

[1] Comptroller, City of Chicago.

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of the every-day operations of life, such as dressing and undressing, for which purpose he had designed a number of clever devices.

A. CULLAMORE[1] said that in training a cripple to earn his living, intense specialization was the keynote. We must not strive to imitate or duplicate nature in any degree, but to find the one best way on the basis of merit alone. We must transcend nature in every case, and that was the job of the engineer. Our problem in vocational training was not to make a man normal, but to take advantage of his abnormality for his own benefit. The cripple thus trained was then a forced specialist and should therefore be treated as such, and instruments should be devised to make his specialization commercially possible and profitable. That was our whole function in this regard.

To every man who had been crippled two things must be shown which were of equal importance to him: first, that he could earn a living; and second, that he could enjoy the living thus earned normally with his fellows. This should be done in the hospital before the change in his normal psychology took place.

D. MCMURTRIE,[2] director of Red Cross cripple work, said that the soldier cripple returned from a life in which he had been relieved from many responsibilities and had been subject at all times to military discipline. The first task, then, would be to rebuild his initiative and his economic responsibility.

The trade chosen for a cripple must first be a growing trade, one that the man could follow in spite of his handicap, and one in which he could hold not one job only, but a thousand. There had been a tendency in providing work for war cripples to devise special lathes and machines; but if that was carried too far, a man who lost his position would be unable to go out and get another job in the labor market.

The day of the pension was past, and it was realized now that the first duty of the nation toward the returned man was not to pay him a pension, but to give him the best possible chance to get and hold a good job.

FRED J. MILLER recalled a statement by a medical authority that a great many men who had had amputations of a limb were

[1] Dean of Engineering, Delaware College, Newark, Del.

[2] Editor, American Journal of Care for Cripples, New York.

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thereby improved physically and mentally, and that they were likely to be more vigorous and better men than they were before. The theory underlying this seemed to be that after the amputation the system still generated as much energy as before and the result was that a greater amount was poured into the remainder of the body and evinced itself in greater activity. He cited a number of cases in confirmation of this opinion, and believed that it had a bearing on the question of whether a maimed limb should be amputated or saved, if possible. From the layman's viewpoint there was perhaps too much anxiety to save limbs that had been injured, when the patients would be much better off without them.

CLARENCE A. WALDO [1] pointed out that some way should be found to conserve and carry to a proper conclusion the valuable work in the reëducation of the cripple that so many national organizations had begun. There was already a great volume of material available which should be analyzed, arranged properly, tabulated, indexed and published for gratuitous distribution.

With two millions of our men under fire, something like eighty thousand would be disabled according to prevailing statistics of casualties at the front. If the Government could partially or wholly restore these cripples to the productive ranks of society this would save a pension tax of $20,000,000 per annum, and as a result this army of 80,000 would be changed from a horde of dependents left to fade away in sickness, gloom and despair into a happy, contented group of cheerful, hopeful citizens.

EDWARD ROBINSON thought that in the education of the cripple not only should his vocational education be considered but his general education as well. The latter was something that took a long time, but the former could be accomplished very quickly with the aid of efficiency methods.

DR. E. E. SOUTHARD [2] said that in working with the feeble-minded it had been his task to determine the minimum amount of brains with which one could do the maximum amount of work. The normal child was not being taught up to the normal in the schools

[1] New York City. Formerly Dean of Engineering, Washington University, St. Louis, Mo.

[2] Psychopathic Department, Boston State Hospital, Boston, Mass.

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but the feeble-minded children were, and it was necessary to work in that direction in the crippled-soldier problem.

There were those who said that one of the great problems was to make the crippled soldier contented, but there really was no happiness that could be regarded as what all wanted. In his experiences with psychopathic cases he had found this to be exceedingly true, and he believed that it would also be the case with the cripple. The primary emotions of fear, anger, sorrow and joy, had each to be treated differently, for each reacted according to its inherent composition. Combinations of these emotions needed very careful attention. The work upon the deficient, upon the crippled, upon those with the minimum of capacity and the maximum output for that capacity was the big problem of efficiency, and the relation of the output to the amount of energy put in would have to be studied along research lines, for from one viewpoint it was the most important thing in sociology.

SARAH COX JOHNSON [1] emphasized the point that we might prepare what we thought was the right occupation or industry for a crippled or maimed man, with the aid of the expert advice and help of the author, but all of that would miss its mark unless the man was saved from himself while he was in the hospital during the period of convalescence. It was necessary that he have his courage buoyed up and his self-reliance helped at the right moment, otherwise his despondency would settle into apathy and his apathy into a state of willing dependence and he would become thoroughly institutionalized. Here was where a woman's intuition played an important part. In the hospital the soldier should be taught his occupation by persons who themselves were craftsmen, and in addition had a general knowledge of the facts of nursing and health and a good grounding in psychology.

F. A. HANNAH spoke of having one client in particular whose business was well adapted to the employment of cripples. The process was continuous, consisting chiefly of machine-tending operations which were comparatively simple and thoroughly standardized. Under his direction the operating requirements of the various machines were being analyzed and specifications drawn, and for many of the machines these could be met by cripples. He asked if anything had been done by the author along these lines.

[1] Department of Charities and Corrections, New York City.

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WALTER N. POLAKOV believed that the problem of employing both industrial and war cripples was absolutely inseparable from the problem of the labor market at large, and he thought that the Society and Governmental, Red Cross and other institutions that were interested in the work should submit the question to the labor organizations.

ARTHUR C. JACKSON was of the opinion that it was necessary to create public opinion favorable to the employment of cripples, so that it would be considered a patriotic action to place them in a workshop especially prepared for their occupation. This could best be done through the widely circulated literary magazines.

JULES AMAR[1] (written). If the purpose of reëducation is to reclassify the wounded man in the social family, the methods must consist in restoring his physical strength by all the resources of therapeutic art; in compensating for his mutilations by devices of orthopedic prosthesis; and, last, in conditioning the work to his comfort.

Two cases confront us: (1) the wounded man who, either because of his wounds or lack or education, is incapable of earning his living; and (2) the wounded man who can earn his living almost as well as before, and who will keep up his former work, in which his past experience is valuable. The latter class is easy to place.

In the first case a change of trade is necessary, and this must be brought about as effectively as possible. Choose *in the same trade* a special branch where the effort of the wounded man will have a chance to produce the best results. Only as a last resort should his former line of work be completely given up, as in that case from 30 to 40 per cent of his earnings is generally lost. An example of this is a mechanic who earned 25 cents an hour and who loses the use of the fingers of his right hand except the thumb. He is made a weaver at 17 cents an hour. The reduction in his earnings is thus 32 per cent — and there are examples of even more ruinous changes.

The combined simultaneous efforts of the engineer and the physician will result in limiting the errors in placing a man in the industries, through an analysis of his qualifications for work. A classification sheet or schedule telling in a few words the aptitude of the man in question is used in the research laboratory under my direc-

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tion. In the first column of this schedule the civilian status of the patient and a clinical description of his wound are given. The second and third columns are reserved for physical and psychological traits. These tentative findings are very simple; for example, one item gives the "thoracic coefficient," or ratio of the height when seated to the height standing; this ratio is, in general, 0.53, and is exceeded only in the case of very robust persons. A value below 0.52 indicates a weak constitution, one unsuited to heavy work.

The cripple's freedom of movement, his useful muscular power and functional capacity are measured with apparatus as exact and reliable as possible, and the apparatus employed for this purpose works in a very satisfactory manner. Furthermore, professional orientation necessitates distinguishing the patients with rapid reactions from those who have slow reactions; this examination is made by means of my *psychographe*. A distinction between the reasons which prompted the man originally in selecting his vocation and the inclinations which he has had since the accident is also noted. Finally character, which is here a moral factor, is taken into account; every workman who has changed employers frequently in a short time is presumed doubtful, or at least of a difficult disposition.

These are the elements which assure the solid basis of reëducation and which call for the combined action of the physician and engineer. I have longed to find these two professions joined in the same person, but am convinced that this would be little short of miraculous.

In practical effort, we have installed in each province of France one or two institutions for reëducation, having at their head a director-general. The technical service is divided between the physician or surgeon — charged with the clinical and orthopedic part — and the engineer, who has the supervision of the workshops. Both collaborate in drawing up the schedule of qualifications referred to above, in appreciating the capabilities of the wounded man, and in deciding upon employment that will be suitable for him.

While the engineer will busy himself in establishing the nature and value of the worker's motions, to simplify and adapt them to the new improvements appearing in tools (finding aid in the remarkable results of Gilbreth and his chronocyclograph), the physisian will apply his orthopedic skill to the needs of practical kinematics. How much I owe to this science for the ameliorations and successes obtained in the invention and adaptation of prosthetic apparatus, the artificial arms especially!

There is no doubt but that the engineer is better qualified than

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any one else in this domain because he possesses the sense of exactitude, the incomparable aid of mathematics and the viewpoint of the mechanic. In addition, however, I should like to see in him an extensive knowledge of psychology, which is so indispensable in the reëducation of war cripples.

Among others who took part in the discussion were HORACE B. DRURY,[1] who warmly commended the author's method of attacking the problem; DR. F. L. MARSHALL,[2] who discussed the possibility of employing cripples in prophylactic dentistry; EDITH M. VALET,[3] who referred to the offer of the New York Branch of the Association of College Alumni to help the Red Cross Institute in its work with cripples; IRENE SYLVESTER, who bespoke a special bureau for war cripples in the Federal employment agency that was under consideration; W. E. SYMONS, who emphasized the part women would play in the reëducation of cripples and cited several instances of marked mental and physical improvement in men who had been crippled; and JAMES F. BUTTERWORTH,[4] who wrote of the very real and urgent necessity in England of proceeding along lines similar to those indicated in the author's recommendations, and deplored the conservative attitude that was responsible for the limited headway that had been made.

THE AUTHOR replied to the salient points of the discussion, particularly emphasizing the fact that the crippled soldier was only a very small part of the crippled population of the country. The industrial cripples, the cripples from birth, from disease and from accident in reality comprised the problem that was ever growing in importance, a problem that included wide and varied considerations. Replying to Mr. Hannah, he stated that the simultaneous motion cycle chart was gotten up with the idea in view of showing all the faculties and all the limits of the worker, who was considered as a society of working members rather than as an individual; and thus a survey of the machine as a demand for motion and a survey of the cripple as a supply of motion would enable one to see whether the two coincided.

[1] Ohio State University, Columbus, Ohio.

[2] 39 Fairfield Street, Boston, Mass.

[3] President, New York Branch of the Association of College Alumni, New York City.

[4] 24 Linden Gardens, Notting Hill Gate, London, W. (See THE JOURNAL, April 1918, p. 313.)

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No. 1630

TOPICAL DISCUSSION ON INSPECTION

THE LOGIC OF INSPECTION

By A. L. De Leeuw, Plainfield, N. J.
Member of the Society

INSPECTION is logical and necessary in our present mode of manufacturing, advantageous to manufacturer and inspector alike. But while Americans have been congratulating themselves because they thought they excelled in interchangeable manufacturing, the fact is that the war requirements have shown that deficiencies exist in the matter of inspection.

2 Interchangeable methods of manufacture is a broad term, because it refers to two rather different things. Products can be interchangeable as far as design or use is concerned, or as far as individual details are concerned. For instance, it makes very little difference when we get a refrigerator of a certain size and make; all of them will fill the bill equally well. In this sense refrigerators are interchangeable. To a certain extent even, perhaps different refrigerators of different makers are interchangeable. This is merely interchangeability of function.

3 But there is another kind of interchangeability. For instance, take the kitchen stove. If one of the lids breaks one simply sends to the maker for another lid which is interchangeable with the previous lid. This is interchangeability of design.

4 On the other hand, two lathes of the same maker will interchange as far as use is concerned, yet may not fully interchange as far as the parts are concerned. For example, I would hesitate to take a carriage from one lathe and put it on another and expect to produce a good piece of turned work.

5 So here are different degrees of interchangeability; interchangeability of the entire product; interchangeability of groups and completed details; interchangeability of the pieces; and then in-

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terchangeability of the details of pieces, such as keyways, screw threads, and so on. In order to accomplish the highest possible in interchangeability, we must take up the matter of inspection.

THE BEGINNINGS OF INSPECTION

6 The time is not far in the past when a complete machine was built and inspected by one man with the only criterion that it should do satisfactorily the work that was assigned to it. Later came the contract system with the foreman as inspector; still later the system of progressive inspection where each workman was the inspector of the previous operation done by another workman; and finally the modern method where inspection is considered an actual operation in the production of parts.

7 One thing that has set our minds against inspection is the fact that some fellow who cannot even run a lathe and does not know the difference between a headstock and a tailstock, actually takes a piece on which an A1 lathe hand has spent two hours and says it is no good, and out it goes. Now, that is very aggravating; nevertheless, we really ought not to blame the inspector if a piece is bad.

8 There is, however, some reason behind our dislike of the average inspector. There are cases where the inspector shows a woeful lack of intelligence. But if an inspector lacks intelligence, we should blame ourselves, because we expect something from him for which we do not pay. The man who does the detail inspecting, for instance, is in effect an unskilled laborer who has been taught one little repetition operation; and if one puts the proposition up to him to decide, say, whether he should reject a shaft when it fails to go in the gage, we are expecting from a laborer what an engineer should decide. If there is doubt as to whether the rejected shaft could not have been used, we should blame the man who set the limits or the man who made the gage, and not the inspector.

SPECIFICATIONS AND INSPECTION

9 The great trouble in the line of inspection is not so much with inspectors as with specifications, and in this connection I am speaking of the detail inspector who makes the interchangeability of manufacture possible. This is a serious subject, and it may not be amiss to tell of a few things that are required of the inspector, for which he has absolutely no training.

10 A few months ago I was in one of the largest aeroplane factories in this country, and saw a man testing the long spruce I-beams

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which form the main beam of the wings. The man inspecting these beams had half a dozen of them laid out on a pair of horses. They were perhaps twenty feet long, and the horses nine or ten or eleven feet apart, a distance that might easily vary from day to day. The inspector laid the I-beams flat — not the way they were to be loaded, but flat! He was very vigorous and took hold of a beam in the middle and pushed it down three or four times; if it cracked he would throw it out. Of six that I saw him inspect, two broke and two cracked. Of course one can blame the inspector, but is not the real blame to be placed upon some one above him who made him do this thing?

11 There is sometimes inspection according to specifications, which is even a little worse. This I can illustrate by referring to certain specifications drawn up for belting which abound in requirements that it would be impossible to check by inspection, as for example, that all butts used in belting shall be of No. 1 selection; that the belting shall be of native packer's steer hide class; that the leather shall be stretched on straight-edged clamps; that centers and sides must be stretched separately; that the scarfing, joining and cementing shall be done by experts; that the finished leather shall be smooth to the touch on both sides; that the leather shall show no excess in the amount of material soluble in water or in ash, etc.

12 This kind of inspection, based upon indefinite or impossible specifications, becomes a matter of much annoyance when it relates to the finish of machine parts. It is up to the inspector to say whether the finish of the machine or of the machine detail meets the ideals of beauty that the public has in its mind. It is exceedingly difficult for an inspector to do this without a standard by which to inspect; and yet I do not believe there are many shops that have standard pieces of finish which from time to time are renewed and inspected by the man who is to be responsible for selling the products.

STANDARDS AND INSPECTION

13 Another instance that has come within my experience further illustrates the difficulty encountered where dependence has to be placed on the judgment of the inspector without an adequate standard for his guidance. A new machine was put into use for making a certain kind of screw heretofore done on another machine. As far as I could see the screws were all right, but the inspector promptly rejected the first one hundred. I sent them upstairs again with the request to hang tags to the individual screws showing

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which were wrong and which were right. Sixty-seven were wrong and 33 were right. I numbered the tags and made a list of those that were wrong. I got out another one hundred screws from the stockroom done on the old machine, and all inspected, hung also 100 tags on them, numbered them from 1 to 200, and made a list of them so that I knew exactly which were the old and which were the new. I sent the 200 screws up to the inspector and he sent them back with his mark as accepted or rejected, and I found that out of the 100 new ones there were now 33 rejected and 67 accepted — just the reverse of the other figures — and of the 100 old ones, which had once been all accepted, 75 were rejected. Now, that is the sort of thing that has to be checked. Really, the inspector was not to blame, because the ground on which he rejected them was roughness of thread, and it is a very hard matter to say exactly twice in succession whether a thing is rough or smooth enough.

14 Inspection does not aim at perfection: its aim is to make the imperfect serve the purpose required. We set limits beyond which the piece shall not go and set as wide limits as possible within which we will receive imperfection. Looked at from this standpoint, it will be found that the office of the inspector is not merely the office of a trouble maker but that he is really a useful member of society.

15 The things that I have mentioned are merely surface indications of a great problem which we have before us. Most of us believe that inspection is absolutely necessary, but as a whole, the problem of inspection is still in the dark and we have not so far tried to put it on its feet. We have not, for instance, laid down standardized rules as to what specifications should be given, say, on the drawings, to enable the inspector to do intelligent inspection without being a professor or a Solomon. We have got to the point where we are willing to make plus and minus allowances, but we have not got to the point yet where we are willing to make the plus and minus allowances as big, or, I should say, as convenient, as possible, because the mere making of a sufficient allowance does not always solve the problem.

16 This is an engineering problem pure and simple. It is the problem of subordinating every piece and every detail, every dimension of the piece to our system of manufacture. Before the drawing is sent to the shop we should have a special inspection in the drawing room, going over every dimension with a view to subordinating it to the system of manufacture in vogue in that shop, and we further should scrutinize that system with a view to its being the most

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economical possible. There are certain things in inspection which make it more likely to be a failure than almost anything else. In the first place, it is a repetition operation. In the second place, there are many things the inspector has to inspect for which he has no absolutely definite data, and he has to follow his own ideas or notions. It is therefore necessary that the inspector should be controlled, and that his inspection should be inspected and checked.

17 We ought to select our inspectors with great care. As a rule we can find them among our workmen. We sometimes find workmen who are not very productive just because their ideas are a little bit strict. Such men may easily be trained into detail inspection. We should try to get the chief inspector as broadminded as possible, but I do not believe it will ever be possible to depend on the broadmindedness of the detail inspector. There should be in the inspecting organization, either in your own shop, or among Government inspectors sent to a job, some man who is enough of an engineer, and also enough of a human being, to have the broadmindedness to look at things not merely from the standpoint of filling certain specifications, but from the broader standpoint of whether or not a piece is useful, because even in Government specifications there are cases where a piece may be useful and still might be rejected on technical grounds.

THE RELATION OF INSPECTION TO PRODUCT

By Frederick A. Waldron, New York, N. Y.
Member of the Society

A COMMODITY is brought into use through the following mental and physical functions:

The Ideal

Idea..... { Invention / Engineering Design

Demand

Manufacture..... { Purchase / Inspection

2 Imagination takes form in the ideal, and ideals are what we fight for. The idea is the ideal in definite form and approaches as nearly as possible the ideal. The idea is developed by invention, followed by design and demand. Manufacturing follows the de-

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mand, which requires purchase and inspection. The inspector is the purchaser's representative, to see that the purchased article is made to drawings and specifications or according to order.

3 As the idea, conceived by the inventor, becomes transformed into the practical design, there exists in the mind of the designer, broad constructive imagination. He conceives space largely from an academic standpoint and ten feet or ten one-thousandths of an inch has no real, definite meaning beyond the dominant feature of the idea. This is one of the principal causes of trouble in inspection and production.

4 Having established the design, the manufacturer takes the drawings and specifications of the designer and materials of manufacturing and completes the article.

RELATION OF MANUFACTURER AND INSPECTOR

5 There are two kinds of manufacturing and inspection: academic and commercial. Academic manufacture and inspection is that which goes back to the original idea of the inventor and designer (neither of whom have had any practical experience), with necessary accuracy in the drawings and specifications.

6 This often results in the products not being manufactured or the manufacturers making an assignment.

7 Commercial manufacture is where the designer can discriminate as to tolerations required, and can visualize the process of manufacture in the specifications to enable the manufacturer and inspector to intelligently comprehend the detail requirements. Under such conditions, the inspector will be helped by the specifications and the manufacturer will be able to produce.

8 Trouble generally exists where the designer and the inspector fail to get together and the manufacturer will be at the mercy of conflicting opinions.

CONDITIONS RENDERING INSPECTION DIFFICULT

9 The condition of design, from the standpoint of manufacture and inspection, is to have liberal and reasonable tolerances so as to permit final functioning. For instance, there may be certain conditions which may have no effect whatsoever on the functioning but which must be held to very closely because the design so specifies. In such cases the inspector is helpless without referring to the designer.

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10 The evil effect of too small tolerances goes beyond the loss to the manufacturer. It reduces the output and places an extra burden on national resources. The effect on the cost, however, is serious. The closer the tolerances, the greater the cost of tools, gages and fixtures required to maintain the product, especially considering the large number of pieces that are being manufactured in this country at the present time.

11 When orders were being placed for only forty or fifty thousand pieces at one time, and an order was being placed but once in two or three years, it was easy to meet academic tolerances and production. But when turning out parts by the million and tens of millions (quantities unheard of before), the wear and tear on the tools and gages is enormous and the manufacture of gages is becoming an industry almost as large as our direct productive facilities prior to the war. Enormous supplies of steel are required to replace scrap losses and tools and gages which have worn beyond the limits of the small tolerances established.

WHAT THE INSPECTOR NEEDS

12 The inspector is not entirely responsible for the above conditions but there are conditions for which he is responsible. Many of these troubles would be obviated if there were closer coöperation between the designer and the inspector and the manufacturer in order that the inspector might know just how far he could go in accepting or rejecting the work and maintain an economic condition of satisfactory manufacture.

13 Complete instructions should come from the designer for the use of the inspector. If the manufacturer is trying to take advantage of the inspector and deliberately makes inferior or cheap work, it is then necessary for the inspector to "put on the screws" for the time being. Some inspectors will lay aside material, in the initial stages of a contract, for some minor defect; they will not pass it and the equivalent of a large sum of money may lie idle for a considerable length of time. After the manufacturer has had his lesson, the inspector will then gradually take material away from the pile and accept it. Meantime, the manufacturer may lack funds to meet his payroll. Where such conditions exist, there is unquestionably blame on both sides.

14 A manufacturer who does not know a snap gage or appreciate what one-thousandth of an inch is and who takes a contract for thousands of duplicate parts, is making a mistake. Under such

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circumstances the inspector is justified in "kicking" and compelling production according to specifications. This is beneficial in the end, especially to those who have had no previous training.

15 It is the purpose of this paper to try to bring the spirit of the designer closer to the inspection department and the mental attitude of the manufacturer to a stage where he regards the inspector as a help and not a hindrance to production.

GENERAL PRINCIPLES OF GOVERNMENT INSPECTION AND RELATIONS BETWEEN INSPECTORS AND MANUFACTURERS

By Col. B. W. Dunn, U. S. A.,[1] Washington, D. C.
Non-Member

IT is of the first importance at this critical stage in our history that harmony should prevail among all important elements engaged in promoting our national defense. Differences of opinion are bound to occur frequently between an inspector and a manufacturer. There is no reason why such differences should be at all serious when both parties are actuated by a desire to be just and reasonable. The differences have been most serious in cases where mutual distrust existed between the parties before the differences occurred. In many such cases this previous absence of confidence has been the principal cause of the difficulty.

GOVERNMENT CONTRACTS AND INSPECTION

2 It seems advisable to explain to you briefly the ordinary development of Government contracts and our methods of inspecting the product. The drawings and specifications for the desired product having been completed by the Design Section located at Washington, the next step is for the Purchase Section to select the manufacturers and negotiate the contracts. In the selection of these manufacturers the Purchase Section is aided by reports from the Production Section relating to the equipment of manufacturers under consideration, their general standing, their technical personnel, their financial standing, etc. Competition among acceptable manufacturers is of course a controlling feature. The contract having been signed, a copy of it, with drawings and specifications, is sent to the Inspection Department and constitutes a notice to this

[1] Inspection Section, Ordnance Department.

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department to take charge of the interests of the Government from that time on.

3 Our Inspection Department at the present time is made up almost entirely of men taken from the manufacturing industry. As a rule, the reserve officers are men who have come into the service purely for patriotic reasons. In accepting these patriotic offers the preference of the Government has been for college graduates with the degree of mechanical engineer, and with a practical experience in machine shops after graduation of five years or more, during which the applicant has received a salary materially in excess of the salary paid by the Government for his grade. The assistants of these officers are civilian employees of the Government obtained through the Civil Service Commission.

4 The inspecting force at a single plant constitutes a field unit. It consists of one officer in charge, known as the Inspector of Ordnance, at the plant. He has as many assistants as necessary, consisting of junior commissioned officers, chief inspectors, assistant chief inspectors, and inspectors. To bring about uniformity in the action of these field units, we have a number of supervising inspectors, made up, as a rule, of men of large experience and mature age, combined with tact and good judgment. These supervisors have a number of plants assigned to them, and they circulate among them, charged with the duty of thoroughly investigating any complaints made by contractors and observing with great care the activities of inspectors to detect any weaknesses. Twice a month these supervisors meet the officer in charge of the inspection service at headquarters to discuss general features of the work and to promote uniformity in the action of the supervisors themselves.

5 From the above, it will be seen that any contractor who has the slightest reason to complain of the action of the Government inspector, can secure at once a complete investigation, and, it is believed, a correspondingly just decision. The inspector of ordnance in charge of the plant is required, in case of a complaint, to immediately get in touch with the chief inspector of the plant and to make a joint investigation. Granted that both minds approach such an investigation in the proper spirit, a satisfactory conclusion should be reached in more than 90 per cent of the cases. The supervisor should settle at least 90 per cent of the remaining cases, and when he cannot secure a settlement, only a few hours are needed to bring to the scene of trouble the principal technical assistant at headquarters, and, if necessary, the officer in charge of the entire service.

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DIFFERENCES BETWEEN GOVERNMENT AND COMMERCIAL CONTRACTS

6 It seems pertinent to analyze to some extent the differences between Government and commercial contracts. The most important one is believed to be the fact that a contractor cannot sue the Government. This is combined with the fact that in practically all Government specifications the contractor is required to satisfy the inspector. The manufacturer who considers an inspector unreasonable must be prepared to prove the accuracy of his charge. If we grant that an inspector is unreasonable, and possibly dishonest, and that his superiors belong to the same family, it is quite evident that the contractor is without adequate protection. The possibility that he may be placed in this position is a source of most of the manufacturer's imaginary troubles, which to him seem anything but imaginary. The absence of personal interest of the inspectors in completion of the contract is another difference between a Government and a commercial bargain. As a rule, the Government inspector has only one responsibility, that of seeing that the quality of the manufacturer's product is up to the prescribed standard. It is no concern of his that the product may be short in quantity. To stimulate production is the duty of another department, the Production Department.

7 Another very important difficulty to the manufacturer relates to the delays that frequently attend the receipt of funds from the Government. With millions to his credit, the Government paymaster cannot deliver the much-needed check until all requirements of rigid red-tape regulations are complied with. This is the cause of frequent trouble to the contractor who undertakes a greater volume of work than his financial backing justifies.

8 Another important difference is found in the fact that in commercial work the contractor is generally more accurately informed on technical matters relating to the product produced than is the purchaser. In the case of Government contracts, it is usually the other way. Few of our manufacturers are ordnance engineers, or have on their personnel staff men who understand the reasons for the requirements of Government drawings and specifications. The barrage fire, which constitutes such an essential part of military operations today, is seriously interfered with by any difference in the action of one fired round from another. Our soldiers will march confidently a short distance in the rear of this wall of bursting fragments, their lives depending upon this uniformity in the ammunition. Any material difference in the weight, exterior form, or loca-

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tion of center of gravity of the projectile, in the action of the fuse, or in the uniformity of the propelling powder charge, would be liable to cause one or more of these projectiles to burst well short of the intended point, and in the midst of, instead of safely in front of, our troops. The contractor who honestly thinks that some nicety of dimension called for by the drawings is introduced solely to allow the inspector to exercise his power, may, in this ignorant way, be objecting to one of the features essential to the efficiency of the ammunition.

REQUIREMENTS FROM GOVERNMENT INSPECTOR

9 The product of the manufacturer is divided by the Government into lots, and for each lot the Government inspector is required to sign a formal certificate, stating in substance that all units of the lot comply in quantity and quality with the requirements of the specification and drawing. It is impracticable for the inspector to inspect each and every unit for each and every requirement. The manufacturer does make a 100 per cent inspection of the product for all dimensions. The plan of the Government inspector is to check the manufacturer's inspection to the extent found necessary, the checked inspection for the more important feature being of course much larger than the less important. The certificate for the Government inspector is required before the voucher for payment of the contractor can be completed.

10 Regarding the kind of coöperation that should exist between the inspection departments of the Government and the contractor, I caused a circular letter to be issued from our Inspection Department to all contractors manufacturing artillery ammunition, asking their views on the suggestion that they submit for each lot of finished product presented for official inspection a certificate on some convenient form signed by a responsible representative of the firm. In this letter it was argued that:

a The certificate does not require any change in the present standard practice other than the signing and filing of the certificate.

b Very exceptional instances have occurred where overzealous or dishonest subordinates have attempted to resort to questionable practices in repairing or salvaging defective material; and where their immediate superiors have disclaimed responsibility because they were ignorant of the practices.

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c The responsibility of the firm in such cases will be acknowledged by no one more promptly than by the management, whose duty it is to take the steps necessary to avoid this ignorance.

d It is believed that this certificate will assist the management in establishing in the minds of all of its employees, and especially in the minds of its shop superintendents, foremen and inspectors, a correct appreciation of this responsibility. It is not conceivable that any of these responsible employees can remain ignorant for any length of time of anything relating to the work and practices under their supervision, if they make proper efforts to keep informed.

e The writer desires the establishment of the most cordial coöperation possible in the efforts of our inspectors and of the contractors to detect and eliminate all defective material, and to prevent errors of judgment in the rejection of good material. Mutual confidence is a necessary foundation for this coöperation. Suspicion will supplant confidence in any plant that does not detect and eliminate the employee who is inclined to conceal rather than to discover and report defects. If it is at all possible to correct the defects and salvage the material by proper, as distinguished from secret or questionable, practices, the Government inspectors will coöperate with the management to that end.

11 While certain of the replies reflected some doubts as to the necessity for such a certificate, the suggestion did receive the hearty approval of the majority of the manufacturers and the form determined upon is as follows:

"We certify that Lot ——— ——— has been
(No.) (Article)
produced by the use of good and modern plant practice; that the components have been inspected carefully by the Inspectors of this Company, and that to the best of our knowledge and belief this Lot complies with all Government requirements that apply to it.

(signed).....
Chief Inspector for.....*Co.*

Countersigned by.....,
Shop Superintendent."

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It should be understood that the above Certificate is not required of any manufacturer who prefers not to furnish it.

12 It is my hope that this discussion will result in developing other practical methods for promoting this coöperation.

MISCELLANEOUS DISCUSSION

SIR CHARLES Ross spoke of the troubles and difficulties which arise between inspectors and manufacturers, and proposed a solution as a basis for discussion. This finally led to the drafting of the following resolution, which was voted upon favorably:

RESOLVED: That the Council of the Society be requested to recommend to the Government the creation of a Board which shall be intermediate between the manufacturer and the inspector, and the Secretaries of War and Navy — the functions of this committee to be as detailed in a resolution offered by Sir Charles Ross and unanimously recommended, viz.:

That authority be given to a committee as follows:

1 It shall hear complaints:

a From manufacturers

b From inspectors.

2 It shall advise inspectors as well as manufacturers upon the proper application of gages and standards of acceptance and rejection.

3 It shall report and have access to the Secretary of War and the Secretary of the Navy.

R. H. DANFORTH called attention to the necessity for the inspection of raw material, citing instances where valuable work had been wasted on soft steel that had become mixed with stock intended to be heat-treated.

A great many specifications today were practically impossible to meet. They called for certain chemical and physical requirements, but in neither was there sufficient leeway to allow for the maximum allowable variation in the other. They were in consequence a constant source of trouble to both the manufacturers of the raw material and the finished product, to say nothing of the inspectors who acted as the go-betweens.

W. S. HUSON thought that it was not so much the inspection itself that must receive attention as it was the specifications, particularly for the guidance of the younger inspectors, who lacked the necessary experience.

The chief inspector must communicate to those under him those qualities which govern proper and intelligent inspection. An in-

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spector must feel that he is not hidebound by his instructions and must use his common sense. He must try to judge the work without bias or partiality and must not permit the workmen to agree among themselves as to what constitutes the quality of work they turn out, nor get into arguments with them as to whether it is right or wrong; he must go to the chief inspector, who must be intelligent and efficient enough to know what constitutes the right kind of work, and how far the tolerances can go one side or the other. In other words, today the principle of good shop inspection is not to point out why work is wrong, but rather to try to point out to the men why it should be right, and thereby gain their coöperation.

C. B. HAMILTON, JR., said that with regard to tolerances it was the practice at his plant to make the limits in the earlier stages of the work less than the Government requirements, and to increase progressively as the later operations are approached until finally they equaled the government requirements. The limits in the early operations should be as close as the men could work to, which would save trouble in the secondary and later operations.

In the matter of specifications we had better assume that the man who wrote them knew more about the work than those who were just starting the work. The modern progress of shell fire called for closer and closer limits, and in munitions manufacture there was no "good enough."

The specifications for belting mentioned by Mr. De Leeuw were in the nature of guidance specifications for the manufacturer to take into consideration in bidding, and the inspector had nothing to do with such specifications.

Many cases were known of shells so rough that the revolution or spinning of the shell made the steel act as a rotary file on the explosive block resulting in premature firing. When they were polished, however, there was no trouble from that cause.

PHILIP REYNOLDS[1] stated that he had seen pictures of guns that had burst, with all the men either killed or wounded, just because some inspector used too much judgment. He believed that inspectors should live exactly up to the requirements, up to the gages, and that matters of judgment should be submitted to their chief. If every one worked on restricted tolerances, that is, lower tolerances than the Government required, there would be very little trouble.

[1] Supt. of Inspection, Lymburner, Limited, Montreal, Canada.

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Regarding the premature explosions which sometimes shattered guns, killing every man on the crew, he believed that they were due to faulty fuses rather than to the cause advanced by Mr. Hamilton.

In the organization of his plant the superintendent of inspection had chief inspectors for each 8-hr. shift, with their assistants controlling each floor or battery of operations. Gaging was performed at the back of machines, the work being conveyed by gravity to inspection bench. All prime dimensions received 100 per cent inspection. Final shop inspection was not necessary with efficient machine inspection except to check parts which were liable to be affected at subsequent operations. All machine inspection was made with restricted tolerances, insuring the acceptability of work by the government with their larger limits.

Each inspector was provided with a small personal stamp which he or she stamped on a location allotted by the government inspector and which did not interfere with the product. By this means any faulty inspection was traced. The assistant inspector checked up his inspectors frequently. Given limit gages which were right, inspectors had no excuse to wrongly gage. All gages were checked daily — and twice daily where necessary — by the gage and standard department, who were held responsible for a sufficient supply of gages and their accuracy. This complete system of inspection had proved very satisfactory in meeting the conditions which existed in the plant.

FORREST E. CARDULLO contended in answer to Mr. De Leeuw that a set of specifications could not be gotten out that would cover entirely, completely and satisfactorily what was needed. No man has sufficient foresight to cover everything that will come up in materials and workmanship and various other things that affect the usability or non-usability of parts. Room has to be left for the inspector to use his judgment, and he should be given authority to waive the specifications. It all depends on whether the thing is just as good for use as if it met the specification in every respect, and if it is it should be accepted.

The purpose of inspection must be to produce the largest possible volume of military implements and munitions that are suitable and usable for their purpose, and the inspection that fails to do this is radically defective. Inspection should be reorganized on the basis of quality and quantity, and inspectors, whether connected with Government or plant, should bear in mind when they are inspecting the

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product of outside manufacturers that they are there primarily to help bring up the general quality, and when that point has been reached they have then done their duty.

Mr. Cardullo confirmed the theory advanced by Mr. Reynolds that premature explosions were due to faulty fuses, stating that this was the consensus of opinion among those at the front.

C. E. COOLIDGE, who had spent two years in a large Canadian plant directing the manufacture of 8-in. howitzers, said that he had obtained the best of results by making it plain to every one of his inspectors that they were part of the government staff, and also advising the chief inspector for the government to take under his wing to a certain extent the company's inspectors. In order to avoid ill-feeling between inspectors and the machine operators, inspectors were assigned to each machine and were told that they must be friendly to the operators and coöperate with them to the limit.

CHARLES E. DAVIS had found that when the fact was established in the minds of the inspectors that the truth was wanted from whatever source it could be derived, friction disappeared and production increased. To his mind it was first necessary to establish in the design of a piece or a machine the vital functioning points of the product to be made, and then to establish the limits of variation that would give these results reliability, and hold to them rigidly.

R. F. BRYANT wrote that when designing gages the class of help to use them should be borne in mind, and also the tolerances on the components of the unit, particularly the maximum and minimum dimensions on parts that were grouped, later assembled into divisions, and lastly into units.

Another important phase of inspection was the eye inspection. For instance, inspectors would agree that a trifling surface defect on a primer made no difference, but because of the fact that the specifications stated that surfaces must be free from defects, they would reject it. Here was a point where care in writing the specifications would do much toward helping the production and would eliminate many discussions.

In planning the organization of the Yale & Towne Manufacturing Company for inspection, the first step was to study the manufacturing methods, because these methods had much to do with the class and kind of inspection and inspectors. To illustrate, automatic-screw-machine production, where the production was from one to five pieces

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per minute, could not be inspected 100 per cent at the machine. In this case several machines were assigned to one inspector, who had a complete set of gages and moved from one machine to the other, giving each piece 100 per cent inspection on each operation.

Hand-screw-machine work was given 100 per cent inspection at the machine. When work was found not to gages the inspector notified the machine setter, and the machine was reset or the tools were reground. After all operations were completed on the components last referred to, the work was placed in receptacles and given a 100 per cent inspection at a central point as a check on the machine inspector. The work was then moved to the assembling department where the final inspection was given by the Government inspectors. This was sometimes 100 per cent inspection and at other times random inspection, depending on the number of rejections found.

The automatic-machine product was moved from the machine room to the inspection room and given 100 per cent inspection by girls. The parts were then inspected by the corps of Government inspectors which consisted of men and girls. The inspection was made at random and varied with the rejections found. The parts were then moved to the assembling benches where they were assembled by the progressive method. Government inspectors were stationed at varying intervals, and the partly assembled fuses were inspected mostly by electric gages.

SAMUEL RUBIN[1] wrote that defects in the interior of metal castings and in welds could be readily discovered by means of radiographs or X-ray photographs. Aluminum offered practically no resistance to the X-rays, and castings of any commercial size could be easily radiographed. Steel, iron, brass, etc., up to 18 in. in thickness were not difficult to radiograph, but a longer exposure was necessary than for aluminum. Paper, cloth, leather, and practically every class of material could be similarly inspected, and by using a stereoscope in viewing a radiograph, the depth of a given defect below the surface of the material might be very closely estimated.

The fact that this method had not been more generally adopted was very probably due to the fear of X-ray burns or the so-called X-ray cancer. However, in fifteen years' work with the Roentgen-ray he had never suffered the slightest inconvenience from this source, having exercised an ordinary amount of care in protecting himself by lead screens.

[1] 322 Crescent St., Harrisburg, Pa.

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The apparatus used in taking X-ray photographs might be of several types, but he used two, one consisting of a 120,000-volt, 5-kw. transformer and an 18-in. induction coil, using either a Coolidge tube or the ordinary gas tube.

DOUGLAS T. HAMILTON, in a communication published on page 247 of THE JOURNAL, March, 1918, wrote, referring to Mr. De Leeuw's paper, that there were few, if any, engineers who did not believe that inspection was the logical and final operation on any manufactured product. The question was, what relation should inspection have to the various machining operations; what form and type of gages should be used; and what manufacturing tolerances were to be permitted?

In the manufacture of high-explosive shells, to take a concrete example, the more important requirements were concentricity of bore, and conformity of shape and weight to Government specifications. A shell not concentric, or out of balance, would not shoot accurately, nor would one in which the center of gravity was so placed that it would not follow the predetermined parabolic curve. Certain Canadian plants had found that a large majority of their rejections on shells made for the British Government were due to the fact that when shells were made to minimum limits for both diameter and length they fell short in the important requirement of weight. This was later corrected by leaving the rear ends longer than necessary and then facing off the ends of the completely machined shells until the desired weight was obtained.

Regarding the specification for belting mentioned by Mr. De Leeuw, Mr. Hamilton wrote that it was not intended for the guidance of inspectors, but as a setting forth of the process by which leather belting could be made in order to meet Government requirements, and as such it would be of value to any manufacturer who had not been previously engaged in this particular line.

A. L. DE LEEUW, replying to Mr. Hamilton in the same issue of THE JOURNAL, wrote that he fully realized that it was entirely out of the scope of the desired discussion to answer the question propounded by Mr. Hamilton except in a very general way, and he had attempted to bring out the necessity of careful consideration of such and other questions. He had not confined himself to the inspection of shells or ammunition because there was no essential difference between the

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rules which should govern the inspection of such materials and those for any other manufactured product.

That it was possible to give tolerances on the dimensions of a shell which conflicted with the tolerances in regard to the weight of a shell showed conclusively that logic was required not merely to determine that there should be inspection, but also that specifications, limits, tolerances, etc., should be given in a logical manner.

Mr. Hamilton had evidently misunderstood his remarks in regard to leather-belting specifications. The instances quoted had been taken from the specifications of users of leather belting; which meant that belting not coming up to these specifications would be rejected by the user. They had not been written by the Government, but by some of the largest private concerns in the country, and were by no means information given by the user to some future belt maker, but instructions to an existing belt maker as to what he would have to furnish. The specifications were of such a nature that there was only one thing to do, and that was to take the word of the maker that he had followed the instructions, for the finished product would not show in any way that the specifications had been met.

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No. 1631

A CODE OF SAFETY STANDARDS FOR WOODWORKING-MACHINE GUARDS

PRESENTED TO THE SOCIETY BY THE SUB-COMMITTEE ON PROTECTION OF INDUSTRIAL WORKERS THROUGH WILLIAM P. EALES, WHO PREPARED THE ORIGINAL MATERIAL CONTAINED HEREIN FOR THE SUB-COMMITTEE'S ACTION

SECTION 1 GENERAL

a There are several fundamentals to be considered in the prevention of work accidents in the operation of woodworking machines: namely,

1 The machines should be properly located in a safe working place

2 The use of the various machines should be limited to the kind of work and the quality or class of material for which they were intended and designed

3 The operators of the machine should be careful and conscientious employees, and thoroughly familiar with the work; likewise, their helpers and fellow employees should be carefully chosen

4 The safety of the employees should be assured, so far as possible, by providing a guard at the point of operation of each machine, and also by enclosing or otherwise protecting all exposed moving parts which may cause accidents.

b Safe Working Place. It is important that the machines be properly spaced to avoid conflict and confusion between the workmen handling stock or material. The location of the machines should be planned so that there will be ample daylight at the point of operation. Artificial lights should be placed to the best advantage to illuminate the workroom, as well as to throw ample light on the ma-

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chines and the material. Woodworking machines are invariably operated at high speed, and whether of the revolving or reciprocating type are likely to cause excessive vibration. For this reason the machines should be installed on the ground floor of the mill or the workshop if possible, and should be secured to substantial foundations or to the floor. The floors should be smooth and level to prevent tripping, and should be covered with non-slipping material at the points where the operators of the machines stand.

c Dust and waste product accumulate rapidly in most woodworking establishments, and it is important that provision be made for the prompt and continuous removal of these elements of danger. Suction exhausts, blowers and mechanical conveyors are peculiarly efficient for the prompt disposal of waste material.

d Suitable Machines. While many woodworking machines accomplish a variety of operations quite satisfactorily, it is difficult to equip them with efficient guards at the point of operation; hence the necessity of removing, adjusting and changing special guards and devices for each operation, which in itself introduces an additional hazard. Wherever practicable, a machine should be selected and guarded for a specific operation; and other work, different in character and involving special hazards, should be assigned to machines suitable for the work.

e Operators should be selected for their fitness as regards quick perception and appreciation of the hazard, good vision, resistance to fatigue, and enthusiasm and enjoyment in the performance of their duties. Beginners and apprentices should receive thorough instruction and training before being permitted to operate machines, and if they show no special aptitude for the work they should be assigned to bench or yard work where there is no machine hazard.

f None but authorized and experienced persons should be permitted to operate machines. Immediately on finishing an operation the machine should be stopped by turning off the power or shifting the belt. For this purpose starting and stopping devices, readily accessible to the operator, should be provided and maintained. Provision should also be made for locking the stopping device or other controlling mechanism, to prevent the accidental starting of a machine.

g It is recognized that the managers of woodworking plants naturally prefer to use wood and lumber in making their own safeguards. While there may be certain advantages at the time, so far as available material is concerned, it must be appreciated that metal

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guards and enclosures for moving parts, if properly installed, do not increase the fire hazard by accumulating dust and becoming saturated with oil. Metal guards are durable and the first cost, while perhaps somewhat in excess of that of home-made wooden guards, should not deter the employer from selecting that which is most permanent and efficient.

h As the high speed of woodworking machines necessitates frequent oiling of bearings, it is necessary that safeguards be easily removable for the convenience of the oiler, and as easily replaced and secured in position.

i Special Woodworking Machines. Standards for machines designed for special operations in the manufacture of vehicle parts, furniture, boxes, woodenware, veneer goods, etc., are purposely omitted. Such machines require special treatment. The same principles will apply, however, and by referring to the standards herein, which cover the machines ordinarily employed in woodworking, it is felt that efficient guards may be easily devised and applied to the unusual types of machines.

SECTION 2 RIP SAWS

a Each circular rip saw shall be provided with a substantial hood securely fastened in position.

b The hood shall completely cover the saw, where the character of the operation will permit.

c Where it is essential that the saw teeth be visible, the guard shall extend forward not less than three (3) inches beyond the point of operation.

d The hood may be adjustable to accommodate various thicknesses of stock. At the rear of saw, and located as close thereto as practicable, there shall be a spreader of a thickness equal to the full width of the saw cut. It should extend above the table the entire height of the saw. The spreader should be attached to the arbor frame; or if the table is immovable, it may be attached directly to the saw table.

e A guard bar shall be provided in front of the feed rolls.

f The driving belt and pulley shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.[1]

g A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

[1] Presented at the Spring Meeting, Cincinnati, Ohio, May 1917, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. See p. 399 of this volume.

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h The dust should be removed by a suction exhaust pipe not less than four (4) inches in diameter. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

i For saws larger than twelve (12) inches, the diameter of the exhaust pipe should be increased not less than one (1) inch for each additional foot of saw diameter.

j The exhaust-hood inlet should effectively guard the saw beneath the saw table.

SECTION 3 BAND SAWS

a The upper and lower wheels shall be completely guarded on the operating side by wire screen of not more than one-half (½) -inch mesh, or its equivalent, so as to effectively prevent accidental contact with the wheels or saw blade.

b An adjustable guard shall be provided at the point of operation, extending from the saw guard to the upper pulley.

c The saw shall be guarded on its up travel between the pulleys at the rear of the saw table.

d A guard bar shall be provided in front of the feed rolls.

e The driving belt and pulley shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery previously referred to.

f A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

g The dust should be removed by a suction exhaust pipe not less than four (4) inches in diameter. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

h For saw blades exceeding two (2) inches in width, the diameter of the pipe shall be calculated on the basis of two (2) inches for each inch in width, or portion thereof, of the saw blade.

SECTION 4 GROOVING, BROAD AND BLIND SAWS

a Sometimes the nature of the work done on these saws is such that a hood guard cannot be used; yet effective protection can be provided by a home-made springboard or block clamped to the table, that will hold the stock to the fence or table and cover the saw.

b The driving belt and pulley shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.

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c A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

d The dust should be removed by a suction exhaust pipe not less than four (4) inches in diameter. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

e The exhaust-hood inlet shall effectively guard the saw beneath the saw table.

SECTION 5 SWING CUT-OFF SAWS

a Each swing cut-off saw shall be provided with a substantial hood or guard to enclose not less than the upper half of the saw.

b A fixed guard or solid enclosure shall be provided at the rear of the saw table for the lower half of the saw.

c A chain or other equally efficient stop shall be fitted to the saw frame, to prevent the saw's swinging beyond the front edge of the saw table.

d The diameter of the saw collars shall be not less than one (1) inch larger than the diameter of the arbor pulley.

e The driving belt shall be guarded by wire screen of not more than one-half (½)-inch mesh, or its equivalent, to a height of six (6) feet from the floor.

f A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

g The dust should be removed by a suction exhaust pipe not less than four (4) inches in diameter. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

h For saws larger than twelve (12) inches the diameter of the exhaust pipe should be increased not less than one (1) inch for each additional foot of saw diameter.

SECTION 6 CUT-OFF, MITER AND VARIETY SAWS

a All saws of these types shall be provided with substantial hoods or covers securely fastened in position.

b The hood shall completely cover the saw, where the character of the operation will permit.

c Where it is essential that the saw teeth be visible, the guard

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shall extend forward not less than three (3) inches beyond the point of operation. The hood may be adjustable to accommodate various thicknesses of stock.

d The driving belt and pulley shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.

e A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

f The dust should be removed by a suction exhaust pipe not less than four (4) inches in diameter. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

g For saws larger than twelve (12) inches the diameter of the exhaust pipe should be increased not less than one (1) inch for each additional foot of saw diameter.

h The exhaust-hood inlet should effectively guard the saw beneath the saw table.

SECTION 7 PLANERS

a The driving belts and pulleys shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.

b A substantial guard shall be provided at the feed end of the planer, in front of the belts beneath the table.

c A guard bar shall be provided in front of the feed rolls.

d A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

e All feed gears shall be encased by solid enclosures.

f The chips should be removed by a suction exhaust pipe not less than six (6) inches in diameter. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

g For planer knives exceeding twenty-four (24) inches in length the diameter of the exhaust pipe should be increased not less than one (1) inch for each additional foot in length of the planer knives, or portion thereof.

h A double-cut planer or surfacer should be fitted with an additional suction exhaust pipe beneath the bottom cutting head. The size of the bottom suction exhaust pipe shall be not less than the requirement for planers, but the diameter of the upper exhaust pipe shall be increased one (1) inch.

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SECTION 8 JOINTERS OR BUZZ PLANERS

a The cutter head shall be of the cylindrical safety type.

b A guard, preferably automatically adjusted, shall be provided to cover the cutter head on each jointer not fitted with a roll feed.

c A guard bar shall be provided in front of the feed rolls.

d The driving belt and pulley shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.

e A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

f The chips should be removed by a suction exhaust pipe not less than four (4) inches in diameter. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

g For jointer knives more than twelve (12) inches long the diameter of the exhaust pipe should be increased not less than two (2) inches for each additional foot in length of knives.

SECTION 9 MOLDING MACHINES AND MATCHERS

a A guard bar shall be provided in front of the feed rolls.

b The driving belts and pulleys shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.

c A substantial belt guard shall be provided at the feed end of the machine.

d The cutting heads shall be covered by sheet metal or other solid enclosure.

e All feed gears shall be encased by solid enclosures.

f A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

g The shavings should be removed by suction exhaust pipes, not less than six (6) inches in diameter for the upper head, and not less than five (5) inches for the lower and side heads. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

SECTION 10 STICKERS

a The cutting heads shall be guarded by a substantial hood securely fastened in position.

b The hood shall completely cover the cutters where the character of the operation will permit.

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c The driving belt and pulley shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.

d A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

e The chips should be removed by a suction exhaust pipe not less than four (4) inches in diameter for each bottom and side head, and five (5) inches for the top head. For knives exceeding six (6) inches in length, the diameter of the exhaust pipe should be increased not less than one (1) inch. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

SECTION 11 TENONING MACHINES

a The cutting heads shall be guarded by a substantial hood securely fastened in position.

b The hood shall completely cover the saw, where the character of the operation will permit.

c The driving belt and pulley shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.

d A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

e The dust should be removed by a suction exhaust pipe not less than five (5) inches in diameter. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

SECTION 12 BORING AND MORTISING MACHINES

a Each boring machine and hollow-chisel mortiser shall be provided with a sheet-metal guard in front of the spindle to prevent accidental contact with the spindle, radial belts or friction drive.

b Safety bit chucks with no projecting set screws shall be used.

c Cotter pins shall be fitted in the ends of counterweight levers.

d Mortising machines shall be provided with adjustable thumb stops.

e The driving belt and pulley shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.

f A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

g The chips from mortisers should be removed by a suction ex-

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haust pipe not less than three (3) inches in diameter. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

SECTION 13 SANDING MACHINES AND SAND BELTS

a The driving belts and pulleys shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.

b A guard bar shall be provided in front of the feed rolls.

c A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

d All feed gears shall be encased by solid enclosures.

e Sanding machines of the drum type should be provided with one suction exhaust pipe not less than six (6) inches in diameter for each roll. For drums exceeding twenty-four (24) inches in diameter the size of the exhaust pipe should be increased not less than one (1) inch for each additional foot of diameter of drum.

f The dust from a *belt* sander should be removed by a suction exhaust pipe not less than four (4) inches in diameter. For sand belts exceeding six (6) inches in width the diameter of the exhaust pipe shall be increased on the basis of one (1) inch for each additional three (3) inches in width of sand belt.

g The dust from a *disk* sander should be removed by a suction exhaust pipe not less than five (5) inches in diameter. For disk sanders exceeding twenty-four (24) inches the diameter of the exhaust pipe should be increased not less than one (1) inch for each additional foot diameter of disk.

h Each *radial-arm* sander should be provided with a suction exhaust pipe not less than four (4) inches in diameter.

i The area of the suction inlet for sanding operations should be twenty-five (25) per cent greater than the area of the exhaust pipe.

j The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

SECTION 14 VERTICAL WOOD SHAPERS

a The cutter heads shall be provided with a guard, cover or hood which will effectively prevent accidental contact with the revolving cutters. The guard may be adjustable to accommodate various sizes of stock.

b The driving belt and pulleys shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.

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c A substantial shield or guard shall be provided for the spindle belt beneath the table.

d A belt shifter, or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

e The chips should be removed by a suction pipe not less than five (5) inches in diameter. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

SECTION 15 PROFILE SWING-HEAD AND BACK-KNIFE LATHES

a The driving belt and pulley shall be guarded as specified in the Code of Safety Standards for Power-Transmission Machinery.

b A belt shifter or a starting and stopping device of some other approved type, shall be provided and located within convenient reach of the operator.

c The chips should be removed by a suction exhaust pipe not less than four (4) inches in diameter. The suction should be equivalent to two (2) inches of water between levels in a U draft gage at or near the suction hood.

d The exhaust-hood inlet shall cover the cutting heads so far as practicable.

Respectfully submitted,

JOHN PRICE JACKSON, *Chairman*
JOHN H. BARR
MELVILLE W. MIX
M. W. ALEXANDER
WM. P. EALES
G. R. OLSHAUSEN
JOHN W. UPP
WILLIAM A. VIALL
CARL M. HANSEN

SUB-COMMITTEE ON PROTECTION OF INDUSTRIAL WORKERS

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No. 1632

NECROLOGY

WILLIAM CHARLES ADAMS

William C. Adams was born in April 1883 in North East, Erie County, Pa. He was educated in the schools there and later attended the State Normal School. He also took a course in the International Correspondence Schools.

He served his apprenticeship as machinist with the Eureka Tempered Copper Works, North East, Pa., from 1902 to 1903. He then located with the Brooks Locomotive Works, Dunkirk, N. Y., as machinist. In 1904 he became associated with the Bantam Anti-Friction Company, Bantam, Conn., as draftsman, and a little later worked in the same capacity for the Coe Brass Manufacturing Company, Torrington, Conn. In 1905 he returned to the Bantam Company as superintendent. In 1908 he took charge of the sewer works of the city of Torrington.

From 1909 until 1914 Mr. Adams was employed by the Chase Rolling Mill Company and the Chase Metal Works Company, Waterbury, Conn., as draftsman and engineer, and designed, constructed and maintained their hydraulic extrusion and rolling-mill machinery. Until the completion of the new plant of the Chase Metal Works Company Mr. Adams had charge of the machine shop, drafting room, pattern shops and hydraulic plant of the Chase Rolling Mill Company. He took charge of the same departments in the new plant.

About March 1915 Mr. Adams became associated with the Kings Norton Metal Company, Ltd., Kings Norton, Birmingham, England, as works manager. He designed and superintended the erection of buildings and plant for the extrusion of non-ferrous metals in bars and sections. As a single unit the plant is regarded by experts as the largest and finest in the British Isles.

Mr. Adams was a member of the Birmingham Association of Mechanical Engineers, the Institute of Metals, London, and was honorary treasurer of the Birmingham Metallurgical Society. He became a member of the Society in 1914. He died on July 13, 1917.

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EARLE C. BACON

Earle C. Bacon was born on May 29, 1859. He served his apprenticeship with the Delamater Iron Works in New York. While there, though but twenty-one years old, he designed the Bacon trunk-cylinder hoisting engine, which had a patented connecting rod with an inside rod for taking up the wear on brasses. This engine was the first used in New York for lifting brick, etc., in building construction, and is still being manufactured for use as a winze hoist and for surface work around mines.

Mr. Bacon served as consulting engineer and furnished machinery for a great many mining companies, as he made a specialty of mining and quarry work. He was at different times consulting engineer for the Davis Sulphur Ore Company, the Sulphur Mining and Railroad Company, Virginia, the Nichols Copper Company, the Lavonia Salt and Manufacturing Company, the Bristol Copper Company, and many others. He was also a pioneer in the asbestos field in Quebec, and designed and equipped the first mill for the reduction of asbestos in that region.

He was a member of the Union League Club and of the Machinery Club. He became a member of the Society in 1885. He died on April 9, 1917.

ARTHUR BEARDSLEY

Arthur Beardsley was educated as a civil engineer at Rensselaer Polytechnic Institute, and was graduated in 1867 with the degree of Civil Engineer. He was then employed for one year as assistant engineer at the Hoosac Tunnel, and in 1868 entered private practice as a civil engineer and architect. In the following year he was appointed instructor in civil engineering, physics and industrial mechanics at the University of Minnesota, and in 1870, professor of civil engineering and industrial mechanics. In 1872 he was called to the chair of mechanics and engineering at Swarthmore College.

Professor Beardsley was elected a life member of the Society in 1883, three years after its organization. He died on January 22, 1917.

ORVILLE G. BENNET

Orville G. Bennet was born in New York City on August 17, 1881. He received his early education in the Horace Mann School and was graduated from Cornell University in 1904.

His first position was with Westinghouse, Church, Kerr and

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Company. He left that firm to become associated with the Ingersoll-Rand Drill Company, where he remained till 1906, when he accepted a position with the American Trading Company, representing it in Japan until 1909, chiefly in the sale and installation of mining machinery. Not wishing to become permanently identified with the Orient, he resigned in 1910 to accept a position with the Akonite Company, New York City. In 1911 he took over the management of the export business of the General Motors Company, later becoming president and general manager. He resigned this position in 1916, and at the time of his death was organizing a company for the distribution of the output of the Nash Motors Company in the state of Texas.

He became a junior member of the Society in 1907. He died on February 28, 1917.

FRANK LEWIS BIGELOW

Frank L. Bigelow was born in New Haven, Conn., on September 21, 1862. He received his education in the same city, attending Hopkins Grammar School and later Yale University. He was graduated from Sheffield Scientific School with the class of 1881, having specialized in dynamical engineering.

Upon graduation Mr. Bigelow entered the shops of The Bigelow Company, manufacturers of fire- and water-tube boilers. He worked in the shops for about two years and in 1883 he was made secretary of the company, later succeeding his father as president. He was also president of the National Pipe Bending Company for the last ten years of his life. He was a director in the Merchants and National Savings Banks and in the New Haven Water Company.

Mr. Bigelow was a member of the American Society of Naval Engineers, a member of the executive committee of the Yale Engineering Association, and was after graduation continuously the secretary of his class, 1881 (Sheffield). He was also president of the Yale Press Association.

He became a member of the Society in 1887. He died in New Haven on June 20, 1917.

ROWLAND SPENCER BROTHERHOOD

Rowland S. Brotherhood was born in September 1875 in Charleston, S. C. He was educated at the Patric Military Institute, Anderson, S. C.

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His apprenticeship was spent with the Betts Machine Company, Wilmington, Del., where he gained his experience in machine-tool designing. In 1902 he accepted a position with the Bethlehem Steel Tool Company, South Bethlehem, Pa., in hydraulic-press and machine-tool designing and on general mill work in charge of the manufacturing drawing office. In 1903 he resigned from this position to become associated with the Portland Iron and Steel Company, South Portland, Me., in general engineering and construction work during the erection of the plant. In 1904 he became connected with the Standard Horse Shoe Co., South Watertown, Mass., as a designer of horseshoe bending and swedging machines. Later in the same year he took charge of the Brotherhood Railway Supply Co., and the following year accepted a position with the Cambria Steel Company, Johnstown, Pa., in the drafting department on boiler, engine, marine and locomotive work and in designing special machinery.

In 1907 Mr. Brotherhood became connected with the Remington Arms-Union Metallic Cartridge Company, Bridgeport, Conn. His position was in the equipment department, where he designed automatic machinery and was assistant to the chief equipment engineer. After five years he resigned to accept a position with the International Silver Company, Bridgeport, superintending the changing of the entire plant over from steam to electric drive, the installation of a new electric-lighting system and the erection of a new building. From April 1913 until the time of his death his work dealt with the general mechanical, electrical and efficiency engineering of the company.

Mr. Brotherhood became a member of the Society in 1916. He was the secretary of the Meriden branch of the Connecticut Section. He died on October 13, 1917.

ADOLPH THEODORE BRUEGEL

A. Theodore Bruegel was born on January 11, 1866, in Canton, O. He was educated in the St. Louis Manual Training School and later attended Lehigh University, being graduated in 1888 with the degree of M.E. He took a post-graduate course in Cornell University and received his M.M.E. degree in 1896.

During the summers of 1883 to 1885 Mr. Bruegel worked as machinist for the Missouri Malleable Iron Works and the Lehigh Valley Railroad Company. He obtained his drafting-room experience with the Johnson Steel Company, Johnstown, Pa. From 1888 to 1892 he acted as instructor in mechanical drawing and descriptive

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geometry in Cogswell Polytechnic College, San Francisco. For the next five years or so he was connected with Sibley College, Cornell University, as instructor in machine design. Later he took charge of the teaching of kinematics of machinery and also junior drawing.

In 1898 Mr. Bruegel became an instructor in mechanical engineering in Pratt Institute, Brooklyn, giving his attention principally to the steam and machine-design courses. From 1907 on he was associated with the Hess-Bright Manufacturing Co., Philadelphia, of which he was secretary at the time of his death.

Mr. Bruegel was a member of the Engineers' Club of Philadelphia, the Society for the Promotion of Engineering Education, the American Association for the Advancement of Science, the National Geographic Society, and the Philadelphia Chamber of Commerce. He became a member of the Society in 1900. He died at his home in Melrose Park, Pa., November 7, 1917.

CHARLES ALEXANDER CANDA

Charles Alexander Canda was born in Summit, N. J., on June 18, 1869. He received his education in the public schools and Stevens Institute, graduating from the latter in 1893. He soon after became associated with the Brush Electric Light Company, New York, where he remained until 1899. During this time he designed a direct-current arc lamp in which the top and bottom carbons were controlled in the head of the lamp.

In the latter part of 1899 he affiliated with the Canda Manufacturing Co., manufacturers of automobiles, serving in the capacities of assistant to the superintendent, acting superintendent in 1900, and superintendent in 1901. Early in 1902 he assumed the duties of secretary and became part owner of the Chrome Steel Works, Chrome, N. J., holding this office at the time of his death.

Mr. Canda was granted a number of patents, among them being a clamping device for tappets, wheels or shaft couplings, and an improvement on a machine for making tubes and tires.

Mr. Canda became a member of the Society in 1916. He died at his residence in Elizabeth, N. J., February 8, 1917.

AUGUSTUS W. COLWELL

Augustus W. Colwell was born in New York City on February 5, 1842, and educated in the public schools and in the College of the

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City of New York. In 1861 he was apprenticed in the machine shop and foundry of his father, Lewis Colwell, starting in the drawing room and later working in the foundry as a molder. He afterwards was general superintendent of the plant and spent portions of each winter in Cuba inspecting the erection of the company's sugar machinery and attending to new orders. On the death of his father he purchased the interests of the other heirs and became president and owner of the Colwell Iron Works, until 1906, when he retired from business. By his numerous inventions and by leading in advanced engineering and foundry practice, he became prominent in English-, French- and Spanish-speaking America as a manufacturer of sugar machinery and apparatus for the manufacture of other products requiring the use of evaporators, as well as steam engines, pumping engines and miscellaneous machinery.

Under his supervision the first successful diffusion battery for handling sugar-cane liquors was erected and operated at the Louisiana Experimental Station located on Governor Warmoth's Magnolia Plantation on the Lower Coast. He was among the first to design and manufacture machinery to use bone char for refining sugar and used it at the plantation for refining direct in one process. He was a pioneer in the use of water-tube boilers on sugar plantations in which bagasse was used as fuel. He patented a bagasse burner for this purpose and installed plants using this fuel on plantations in Cuba. His system of returning all exhausts and drips to the boiler house and utilizing the exhaust steam for the vacuum pan and triple effect was much sought for by the planters.

He also was one of the first engineers to advocate clarifiers, steam trains and centrifugals to take the place of the old open kettle direct-fired as used by the earlier sugar makers. He remodeled many old-style plants on sugar plantations by supplying centrifugals to eliminate the molasses from the magma after it left the vacuum pan. By contrast, the old cone molds and banana-leaf molds which were common at that time had to be stored for weeks in dark cellars and allowed to drain in order to eliminate the molasses.

A great deal of interesting work was done by Mr. Colwell in fields totally different from those which engaged his chief attention. He patented and erected for New York City refuse crematories which were used by the late Colonel Waring when he was Commissioner of Street Cleaning. He did the steel and iron work for a number of lighthouses erected on the Atlantic and Gulf coasts. He made many experiments for the United States Government in the interest of the

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sorghum industry, designing and operating the machinery, and also furnished much machinery for the glucose trade. It is interesting to note that Lewis Colwell, his father, was the first to use coal in a cupola to melt iron, and that similarly he was the first, in New York City, to use coke in a cupola.

During the Civil War, in spite of the fact that the Colwell Iron Works was actively engaged in Government work and maintained a shipbuilding yard in Jersey City where several monitors were constructed, Mr. Colwell enlisted twice with the 137th New York Volunteers and was honorably discharged as color sergeant. About 1886 he was made commander for the term of two years of the John A. Dix Post 135 of the Grand Army of the Republic.

Mr. Colwell was one of the charter members of The American Society of Mechanical Engineers and signed the register at the first Annual Meeting. He died on January 2, 1917.

JOSEPH PHINEAS DAVIS

Joseph P. Davis was born on April 15, 1837, at Northboro, Mass. He was graduated from Rensselaer Polytechnic Institute in 1856 with the degree of C.E. Until 1861 he acted as assistant engineer on the construction of the Brooklyn Water Works. He then went to South America, where he remained for four years in the employ of the Peruvian Government as topographical engineer. Upon his return he was made commissioner of parks in Brooklyn, N. Y.

About 1867 he was appointed chief assistant engineer on the construction of the St. Louis Water Works, later becoming chief engineer on the construction of the Lowell, Mass., Water Works. In 1872 he was appointed chief engineer of the Boston Water Board, and the following year was made city engineer of Boston, which position he held till 1880.

At that time Mr. Davis accepted a position with the American Bell Telephone Co. as chief engineer, holding the same position with its successor, the American Telephone and Telegraph Co., until 1905, when he retired from active business.

Mr. Davis was the consulting engineer of the Croton Aqueduct Commission from 1884 to 1886, of the Massachusetts State Board of Health from 1886 to 1904, of the Metropolitan Sewerage Commission, Mass., in 1898. He was vice-president and general manager of the Metropolitan Telephone Company, New York, from 1880 to 1886, and was president of the Hudson River Telephone Company

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from 1889 to 1895, and of the Westchester Telephone Company from 1890 to 1903.

Mr. Davis was a member of the American Society of Civil Engineers, the American Institute of Electrical Engineers, the Institution of Electrical Engineers, England, and the Boston Society of Civil Engineers. He became a member of the Society in 1880. He died on March 31, 1917.

WILLIAM L. DIERMAN

William L. Dierman was born on May 19, 1868, in Ghent, Belgium. He was educated in the College of Toulouse, France, and the College of Richmond, in London, England. In 1887 he received the degree of C.E. from Ghent University and in 1888 the degree of E.E. from the Montefiore Institute, Liège, Belgium.

Upon the completion of his engineering course he became associated with the Société Générale Electrique and was located first in Paris and afterward in Lille, France. It was while with the Société that he had charge of the building of tramways in European Russia and the Caucasus.

He was next connected with the Société Eclairage et Transmissions Electriques à Longue Distance, where his duties consisted in designing dynamos, machinery and electrical plants. In 1890 he was commissioned by the Belgian Government to make a report on the electric traction of the United States. In 1891 he was made supervising engineer of the electric-traction department of the Compagnie Internationale d'Electricité, Liège. He was the designer of the electric-traction system of the Liège and Herstal Street Railway and of many other minor systems. He was the supervisor of the installation of the electric system in Liège. From 1893 to 1901 he was general manager of the concern of Dierman and Company, Liège, which later became the Société des Applications de l'Electricité in Liège. In 1901 he located in Brussels, where he acted as consulting engineer for the Compagnie Générale de Construction, Paris, Ateliers Rateau Muysen-Malines, and Ateliers de Construction de Blane Misseron, designing electrical and mechanical plants for these companies.

Since the war he has been purchasing manager in New York for the Eclairage Electrique of Paris. In this connection he directed the purchase of machine tools and machinery for new works in France. He was the administrateur délégué for Belgium of his

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concern. He also maintained a private office as consulting engineer in Brussels.

Mr. Dierman was a member of the Société des Ingénieurs Civils de France. He became a member of the Society in 1915. He died on December 25, 1916.

CHARLES EUGENE WILLEY DOW

Charles E. W. Dow was born in Manchester, N. H., on April 25, 1859. He was educated in the public schools of that city, and commenced his professional work there by the acceptance of a position as draftsman with the Amoskeag Manufacturing Company.

He held successively the positions of chief draftsman with the Brown and Sharpe Manufacturing Company, Providence, R. I.; mechanical engineer with the Hotchkiss Ordnance Company, also of Providence; agent for the Metallic Drawing Roll Company, Indian Orchard, Mass., and manager of the American Bolt Company, Lowell, Mass.

Mr. Dow was widely known in the textile industry of this country, having been closely associated with these manufacturers in humidification work and air conditioning for about fourteen years. At the time of his death he was consulting engineer and vice-president of the Elbert Clarke Company, engineers, of Rochester, N. Y.

He was a member of the New England Cotton Manufacturers' Association. He became a member of the Society in 1911. He died on June 16, 1917.

GEORGE LELAND FALES

George L. Fales was born on May 18, 1878, in Nashua, N. H., and was educated in the grammar and high schools there. His technical education was acquired through self-study.

For two years he was in charge of the power plant of the Bayley Hat Manufacturing Company, Newburyport, Mass. His next position was with the G. R. & I. St. Ry. Co., Georgetown, Mass., as chief engineer of its 1200-hp. power plant. In September 1899 he was made chief mechanical engineer of the Boston Almshouse and Hospitals, Boston, Mass. In 1904 he resigned to take the position of chief engineer and electrician with the Great Northern Portland Cement Company, Marlborough, Mich., where he had charge of the power plant and mill equipment of motors, air compressors, etc. The following year he became connected with the Hudson Portland

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Cement Company, Hudson, N. Y., as chief engineer and electrician, having charge of the power plant and electric equipment. In February 1906 he was made superintendent of the power department of the Tennessee Copper Company, Copperhill, Tenn., having charge of all power plants of the company, aggregating 10,000 hp. in steam, electric, compressed-air and refrigerating machinery. In 1916, after ten years with the Tennessee Copper Company, he resigned to take the position of chief engineer with the Raritan Copper Works, Perth Amboy, N. J., which position he was holding at the time of his death.

Mr. Fales was a master operating engineer, a member of the Institute of Operating Engineers, and a member also of the National Association of Stationary Engineers. He became an associate-member of the Society in 1914. He died on December 29, 1917.

FRANK FIRMSTONE

Frank Firmstone was born in Glendon, Pa., on August 29, 1846, and received his early education at the Phillips School, Easton, Pa. From there he went to the Saunders Military Academy, in Philadelphia, and in 1865 was graduated from the Polytechnic College of Pennsylvania as a mining engineer.

His first position was with his father in the Glendon Company, and he was associated with this firm for over twenty years. Upon the death of his father in 1875 he became general manager of the company. He resigned in 1887 and soon after became associated with the Cranberry Iron and Coal Company, Cranberry, N. C. He was president of this company for a number of years and was a director of all its subsidiary companies until the time of his death.

He was a recognized authority on engineering matters, and contributed valuable papers on blast-furnace practice to the American Institute of Mining Engineers.

Mr. Firmstone was a member of the American Institute of Mining Engineers, the American Society of Civil Engineers, the American Society for Testing Materials, the American Forestry Association, and the Engineers' Club of New York.

He became a member of the Society in 1880. He died on June 27, 1917.

CHARLES FITZGERALD

Charles Fitzgerald was born in Monroe, N. Y., on October 1, 1859. He received his early business training and experience with

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the Ramapo Car Wheel Company, in whose employ he worked from 1879 to 1882, leaving that firm to accept a position with John Roach and Sons, Chester, Pa.

His next position was with the American Ship Building Company, Philadelphia, where he was the foreman in charge of the erection of marine engines. From 1885 to 1889 he worked with Robert Wetherill and Company as outside erection engineer. He was next associated with the Citizens Traction Railway Company as chief engineer, and later as general superintendent of that company and the Consolidated Traction Company, Pittsburgh, Pa. In 1902 he accepted the position of mechanical engineer with the firm of Booth and Flinn, Pittsburgh. In 1906 he became general manager of the Brazilian Dredging Company, Brazil, South America. At the time of his death he was assistant to the president of the Pittsburgh Valve Foundry and Construction Company.

Mr. Fitzgerald became a member of the Society in 1912. He was also a member of the Engineers' Society of Western Pennsylvania. He died on June 2, 1917.

CHARLES S. FOLLER

Charles S. Foller was born in Buffalo, N. Y., on May 9, 1876. He attended the public schools of that city, and upon being graduated from the high school went to Hobart College, Geneva, N. Y., for a year. He also took special work in Cornell University.

He served an apprenticeship of one year at the machinist's trade with the Lake Shore and Michigan Southern Railway. He was then employed in the drafting room of the Brooks Locomotive Works, Dunkirk, N. Y., afterward accepting a position with the Pittsburgh Locomotive Works as chief draftsman, shortly being advanced to superintendent of frame work in the shops. From 1897 to 1905 he was connected with the designing department of the American Locomotive Company, and at the close of that period was the principal designer of new locomotives of the company. For about a year he was engaged in designing steel cars with the Standard Steel Car Company, Pittsburgh, Pa. For the last twelve years of his life Mr. Foller was associated with the Union Spring and Manufacturing Company, Pittsburgh, Pa., first as mechanical engineer and then as western sales manager, in charge of the office in St. Louis, Mo. In the summer of 1913 he returned to the headquarters of the company at Pittsburgh as general manager of sales.

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Mr. Foller was a member of the Engineers' Society of Western Pennsylvania and the American Society of Testing Materials. He became a member of our Society in 1906. He died in Pittsburgh on December 30, 1917.

HENRY RUTGERS FORD

Henry R. Ford was born on January 30, 1871, in Lawrenceville, Pa. He was educated in Binghamton, N. Y., attending both the grammar and high schools of that city. Later he took the engineering course at Pratt Institute, Brooklyn.

After serving his apprenticeship as electric wireman and as machinist, he obtained a position with the Edison Electric Illuminating Company, New York City, as wireman. In 1893 he was employed by the F. P. Little Company, Buffalo, N. Y., in the capacity of wireman and machinist, later becoming foreman and superintendent. In 1898 Mr. Ford became associated with the firm of McCarthy Brothers and Ford, giving special attention to designing, general engineering and contract work. Throughout Buffalo and its vicinity he designed and installed many steam- and gas-power and lighting plants.

He became a member of the Society in 1914. He died on October 31, 1917.

ALBERT FREDERICK GANZ

Albert Frederick Ganz was born in Elberfeld, Germany, April 25, 1872, and came to this country with his parents in 1881. After attending private and public schools he entered the College of the City of New York in 1886, and completed the first year's work in the mechanical course. For the next four years he was employed in the electrical works of Bergmann and Company, New York City, and of the Edison General Electric Company, Schenectady. During this time he attended the Cooper Union Night School. He entered Stevens Institute of Technology as a member of the sophomore class in 1892 and was graduated in 1895 with the degree of Mechanical Engineer. Immediately after graduation he was appointed instructor in applied electricity; two years later he was advanced to the position of assistant professor of applied electricity and physics; and in 1902 he was appointed professor of electrical engineering and head of the department. With the appointment of class deans in 1908, he became dean of the senior class. The period of Professor Ganz's

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connection with Stevens — 1895 to the present — coincided with the phenomenal advance in the theory and practice of electrical engineering, and it is mainly due to his study and efforts toward improvement that the electrical course was kept abreast of the times, and that so many graduates of Stevens have been fitted for responsible positions in the electrical field.

Professor Ganz was widely known in the engineering world, having made many commercial and scientific tests and investigations. He had made a special study of methods for mitigating corrosion of underground structures by electrolysis and was a national authority on this subject. He contributed many valuable scientific papers to technical societies and journals.

Professor Ganz was a fellow of the American Institute of Electrical Engineers and of the American Association for the Advancement of Science, and a member of the following societies: The American Society of Mechanical Engineers, American Gas Institute, American Electrochemical Society, The Society for the Promotion of Engineering Education, Illuminating Engineering Society, American Water Works Association, National Electric Light Association; and past-president of the New York Electrical Society. He was also a member of the Hoboken Board of Trade, the Engineers' Club and the German Liederkranz of New York, and of the Tau Beta Pi fraternity.

Professor Ganz became a member of the Society in 1910. He died on July 27, 1917.

E. W. GRIEVES

E. W. Grieves was born in Delaware in 1843 and attended the public schools in that state. He spent a four years' apprenticeship at woodworking, and then served several years as a patternmaker on ship and car work and as a designer and constructor of cars.

He became the chief draftsman and assistant superintendent of the shops of the Harlan and Hollingsworth Company. Later he was associated with the Baltimore and Ohio Railroad as master car builder. At the time of his death he held the position of mechanical expert with the Galena Signal Oil Company, Franklin, Pa.

Mr. Grieves became a member of the Society in 1891. He died in February, 1917.

EDWIN J. HADDOCK

Edwin J. Haddock was born in Mount Vernon, N. Y., June 13, 1868. He was educated in the schools of New York City. He

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obtained his early experience in the shops and drafting rooms in the vicinity of New York, completing this training with seven years spent under the immediate direction of Thomas A. Edison.

He held successively the positions of chief draftsman of the Robins Conveying Belt Company, New York City; chief engineer of the Jeffrey Manufacturing Company, Columbus, Ohio, and chief draftsman of the Tennessee Coal, Iron and Railway Company, Birmingham, Ala. Later he engaged in private practice in Milwaukee, Wis., building numerous stone-crushing plants in that region. At the time of his death he was chief engineer of the Edgewater Steel Company, Pittsburgh.

He became a member of the Society in 1906. He died April 11, 1917.

CLINTON A. HAMILTON

Clinton A. Hamilton was born on October 5, 1873, at East Orange, N. J. He was a graduate of the high school of East Orange. He served a three-years' apprenticeship in the E. P. Allis Company's shops at Milwaukee, and then went to Pittsburgh to take a position with the National Tube Company. When he severed his connection with this firm he entered into consulting engineering in New York City, under the firm name of McClave, Hamilton and Remmer. Later he became general sales manager for the International Steam Pump Company, with headquarters at Pittsburgh. In 1906 he accepted the position of vice-president and general manager of the Wisconsin Engine Company, Corliss, Wis., and remained with this company for about six years, resigning to accept the position of vice-president and general manager of the Lavine Steering Gear Company, Racine, Wis. In 1913 he became president and general manager of the Racine Manufacturing Company, and retained this position until 1916, when he formed a partnership with Mr. James Cram and took over the sales agency of the Allen Motor Car Company. He was connected with this company at the time of his death.

He became a member of the Society in 1908. He died on March 12, 1917.

J. ANSLEY HARTFORD

J. Ansley Hartford was born in Pittsburgh, Pa., on October 17, 1871. He received his early education in the public schools of Pittsburgh, and was graduated from the Pittsburgh Central High

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School at the age of sixteen. He served a four-year apprenticeship as machinist at the Black Diamond Steel Works. He spent the next five years with the Westinghouse Electric and Manufacturing Company, entering as a machinist and being promoted through the tool-making division to the position of outside construction engineer, working on some of the largest power installations in the country.

In the meantime he had studied mechanical and electrical engineering out of business hours, and was given charge of the electrical equipment of the Westinghouse Machine Company at East Pittsburgh. He remained at Pittsburgh eleven years in the capacity of factory engineer responsible for all service machinery. He designed the switchboard in use at the Pittsburgh plant. He represented the company in its joint betterment work with the Westinghouse Electric Company, organizing the Casino Technical Night School, Casino Restaurant and Library.

In 1910 he accepted the position of superintendent of design and manufacturing of the tractor works of the Smith Manufacturing Company, Chicago. Later he designed the Breese motor plow and became secretary and general manager of the company organized to manufacture it. In February 1916 he accepted the position of experimental and productive engineer with the Garford Motor Truck Company, which he held at the time of his death.

Mr. Hartford became an Associate of the Society in 1914. He died at Lima, Ohio, on March 17, 1917.

FRANK EUGENE HOLT

Frank Eugene Holt was born at Holyoke, Mass., in 1856. He served his apprenticeship with Eddy and Stone, of Worcester, Mass., and between 1876 and 1893 was associated with the Washburn and Moen Manufacturing Company, during which time he was in charge of their Union Street shop and also employed in the erection of rolling mills for that company. In 1893 he accepted the position of master mechanic with the Spaulding and Jennings Company, and later, when this plant was absorbed by the Crucible Steel Company of America, he was engaged by the Singer Manufacturing Company to design and erect a rolling mill to produce small steel shapes. Afterward he was put in charge of the power houses of the company at the Elizabethport factory, acting also as adviser on power matters for their plant at St. Johns, Canada.

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At the time of his death Mr. Holt was president of the Singer Club, and a member of the Singer Engineering Society. He joined the Society in 1900. He died on February 4, 1917.

AUGUST A. HONSBERG

August A. Honsberg was born on May 18, 1841, in Boulay, Metz, France. He was educated in France, receiving his technical training in the Institution Carmentrez.

He served an apprenticeship from 1859 to 1861 with Kaut and Westmayer at St. Jean, Saarbrucken, Germany. The next two years he spent at the Ateliers des Chemins de Fer de l'Est, Montigny. He obtained his drafting experience in the Regimental School of Engineers from 1863 to 1865, leaving there to go to l'Ecole Polytechnique, Metz. In 1866 he became superintendent of machinery at the Arsénal de Génie. He served during the Franco-Prussian War as chief of the engineering detachment, Fifth Army Corps.

About 1872 Mr. Honsberg came to the United States. His first position was with the Kings Bridge Company, and he was later associated with the Keystone Bridge Company. In 1881 he became master mechanic in charge of the machinery and buildings of the Cleveland Rolling Mill Company. After ten years' service he resigned to take a position in the Cleveland city engineer's office in the bridge department, leaving this department after another ten years to enter the city water-works office for the purpose of making plans for a new pumping station, engine and boiler house. For the last six years of his life he was connected with the bridge and map department of the city of Cleveland.

Mr. Honsberg was a member of the Cleveland Engineers' Society, and became a life member of the Society in 1901. He died on October 21, 1917.

O. ZELL HOWARD

O. Zell Howard was born in Raleigh, N. C., on December 6, 1876. He was graduated from Lehigh University with the class of 1896, and during the next year was employed in the shops of the Crawford Manufacturing Company, Hagerstown, Md.

His drafting-room experience was obtained with the Newport News Shipbuilding and Dry Dock Company, where his work dealt with marine-engine and boiler drafting. His next position was with the Baltimore Smelting and Refining Company on general machine

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drafting. In 1900 he turned again to marine-engine and boiler drafting with the Maryland Steel Company, Sparrows Point, Md. For about a year he was connected with the Bureau of Construction and Repair, Navy Department, Washington, D. C., on auxiliary machinery, resigning to take the position of mechanical engineer with the American Carbide Lamp Company, Philadelphia, Pa. In 1902 he became an instructor in the department of marine engineering and naval construction in the United States Naval Academy, Annapolis, Md. He assisted the head of the department in preparing textbooks on naval engines and machinery and on mechanical processes. He also assisted in the laying out and the superintending of the erection of experimental turbines and boilers in the Naval Experiment Station at Annapolis, and in making tests on the machinery already erected. For the last three years of his life he was supervising engineer of the Diamond Match Company.

Mr. Howard was a member of the American Society of Civil Engineers, the American Institute of Electrical Engineers and the Society of Naval Architects and Marine Engineers. He became a member of the Society in 1908. He died on December 20, 1917.

CHARLES EDWARD HYDE

Charles E. Hyde was born in Bath, Me., November 26, 1855. He attended the public schools of Bath, and, when graduated from the high school there, spent the next three years in the Worcester Polytechnic Institute. The last year of his course was taken in the Massachusetts Institute of Technology. The year after his graduation he spent in Europe for the purpose of examining the shipyards and engine works of the old country, obtaining valuable information in his specialty.

Upon his return he worked as machinist in the Portland Machine Shops, and then as draftsman in the Columbian Iron Works at Baltimore, Md. He was next employed in the drawing office of Cramp's Shipyard, Philadelphia, Pa., and later was chief draftsman for Ward, Stanton and Company, Newburg, N. Y., builders of all types of fast vessels. This last position afforded him the advantage of working with Mr. Stanton, who was noted for his ability as a designer of marine engines.

Returning to Bath in 1884, he entered the employ of the Goss Marine Iron Works as chief draftsman and superintendent, and during his service there he introduced the practical use of the triple-expansion

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engine, the first to be employed in this country. When this company changed ownership, he was employed by the Bath Iron Works, and was chief draftsman and constructor of the engines of the *Castine*, *Katahdin* and *Machias*.

After leaving Bath he became general manager and president of the New London Marine Iron Works, at New London, Conn. For the last few years of his life he was engaged in business in New York City.

He was a member of the Society of Naval Architects and Marine Engineers and of the Engineers' Club of New York. He became a member of the Society in 1885. He died May 19, 1917.

JOHN SEDGWICK HYDE

John Sedgwick Hyde was born in Bath, Me., March 25, 1867. He was a graduate of the Massachusetts Institute of Technology, class of 1888. He was connected with the Bath Iron Works, Ltd., in the successive capacities of apprentice, draftsman, paymaster, assistant superintending engineer, superintendent, vice-president and general manager, and from 1905 as president of that company. He was a director of the Maine Central Railroad.

Mr. Hyde was a member of the New York Engineers' Club, the Society of Naval Architects and Marine Engineers, the American Society of Naval Engineers, and the Institution of Naval Architects of Great Britain. He became an associate of the Society in 1892. He died at St. Augustine, Fla., March 17, 1917.

WILLIAM THOMPSON ILER, JR.

William T. Iler, Jr., was born in New York City on June 28, 1892. He was educated in the public schools of the city and was graduated from the Stuyvesant High School. In June 1915 he received his degree in mechanical engineering from New York University.

During the summer of 1913 he worked under the Heights of Buildings Commission in New York as engineering draftsman, and in the following summer served as rodman and assistant topographical draftsman in the Department of Public Works in New York. He obtained his shop experience in the shops of H. W. Johns-Manville Company, Bound Brook, N. J. Later he became assistant junior engineer with Gunn, Richards and Company in Utica, N. Y. At the

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time of his death he was holding the position of assistant manager of the Slocum, Avram and Slocum Laboratories, N. Y.

He became a member of the Society in 1916. He died on October 18, 1917.

WILNER E. JOHNSON

Wilner E. Johnson was born on May 16, 1881, in Sweden. In 1903 he began his apprenticeship with the Brooklyn Rapid Transit Company as a draftsman in its 52d Street shop. He became chief draftsman in 1907 and engineer of car equipment in 1911. In 1913 he accepted the position of engineer of car construction with the allied New York Municipal Railway Corporation.

In 1912 Mr. Johnson made a country-wide study of car designs in relation to speed of passenger interchange, the direct result of which was the development and adoption of the center-entrance type of car, which later became a model for many other roads. Mr. Johnson's most noteworthy achievements for his company were the detailed working out and development of the Brooklyn center-entrance surface car and the New York Municipal Subway car.

As a member of the committee on equipment of the American Electric Railway Association, he spared no effort to make the committee's researches and standards of real value and of active interest to the industry at large.

Mr. Johnson became a member of the Society in 1914. He died on July 27, 1917, at his home in Brooklyn.

ROSCOE B. KENDIG

Roscoe B. Kendig was born in Renova, Pa., March 3, 1868. He received his education in the home schools. He began railway work in 1884 as a messenger boy in the employ of the Pennsylvania Railroad. From 1885 to 1890 he served as machinist apprentice, and until 1893 as draftsman at Renova. The next seven years he held a position as draftsman in the office of the superintendent of motive power of the Pennsylvania Railroad at Williamsport, Pa. In 1900 he was appointed chief draftsman of the Lake Shore and Michigan Southern Railway at Cleveland, Ohio, and in 1904 he became mechanical engineer of the same road.

He held this position until 1910, when he was appointed general mechanical engineer of the New York Central Lines at New York City, and in 1912 he became chief mechanical engineer of the New

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York Central Railroad, which position he held at the time of his death.

He was a significant factor in the development, design and construction of the Collinwood shops of the New York Central Railroad. While he was mechanical engineer of the Lake Shore and Michigan Southern road, the modernization of the locomotive terminal facilities was undertaken under his immediate supervision. Large modern engine houses were erected at several points, many features of which served as a model for later construction of this nature.

The design and construction of the rolling equipment of the New York Central Railroad, including both passenger- and freight-car equipment and locomotives, from 1910 were under his immediate supervision, and showed in their development his keen appreciation of the necessities of the future. He was from 1904 an active member of the American Railway Master Mechanics' Association, and from 1905 of the Master Car Builders' Association. He was a member also of the American Society for Testing Materials and of the Engineers' Club of New York.

He became a member of the Society in 1913. He died May 10, 1917, at Detroit, Mich.

PAUL H. KENDRICKEN

Paul H. Kendricken was born in Galway, Ireland, in 1834. He set sail for America as a lad of seven, and landed in Boston in 1842.

In 1852 he went as an apprentice to Walworth and Nason, then considered pioneers in the steam and hot-water heating of houses, and afterward became associated with the Union Steam Gauge and Low Water Detector Co. In 1859 he was put in charge of the steam works of the Massachusetts Steam Heating Company, and was later promoted to the position of acting superintendent.

Not long after, he entered the U. S. Navy as third assistant engineer, was later made second assistant engineer, and remained in active service until the end of the Civil War. He then became associated with Clagston and Company for whom he acted as superintendent. After some changes the firm became Ingalls and Kendricken, and under Mr. Kendricken's guidance developed into a successful business. The firm was incorporated in 1905 and Mr. Kendricken acted as president and treasurer until the time of his retirement in 1912.

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Mr. Kendricken held various public offices, including that of councilman, alderman, state senator, park commissioner for the City of Boston, etc. He was also a member of the Executive Committee of the National Association of Master Steam Fitters.

He became a member of the Society in 1910. He died on February 5, 1917.

ALFRED EUGENE KENRICK

Alfred E. Kenrick was born in Brookline, Mass., on February 15, 1851. He was educated in the public schools of that town, and started his apprenticeship at the age of sixteen. In 1885, having learned his trade, he entered into partnership with his father in the firm of Kenrick Brothers.

His most successful piece of engineering work is considered to be his invention of the water-heating system for the Brookline Public Bath House.

Mr. Kenrick was an active member of a number of societies in connection with his work. In January 1907 the American Society of Heating and Ventilating Engineers presented him with a silver loving cup in token of his services to that society. He held during his membership in the Master Steam and Hot Water Fitters' Association of the United States every office within its gift, and on the twenty-fifth anniversary of the Association, in 1913, he was presented with a silver pitcher and salver in appreciation and recognition of his fidelity. He was a member also of the Master Plumbers' Association of Boston.

For over twenty years he served the town of Brookline as a member of its appropriation committee, and for nearly thirty years he was associated with the Brookline Savings Bank as vice-president and a member of its board of investment.

He became a member of the Society in 1896. He died on January 17, 1917.

WILLIAM LODGE

William Lodge was born in Leeds, England, in 1848, the son of George Lodge, a skilled mechanic in the textile industry, and had the advantages of a common-school education. After serving his apprenticeship in the shops of Fairbairn and Company, Leeds, he came to Philadelphia, where he worked for Chambers Brothers from 1869 to 1872, making paper-folding machinery. He went to Cincinnati in 1872 and worked for Steptoe, McFarlan, Nottingham and Company

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for eight years, first as a journeyman machinist and later as a foreman. Having saved $1000, he formed a partnership with William Barker, under the title of Lodge and Barker, the firm starting in business early in 1880 as machinists.

Beginning with $1000, the business inventoried at the end of ten years $400,000. Fifteen months after starting they employed 75 men. There is little doubt that this rapid success induced quite a number of the better and more ambitious mechanics in Cincinnati to take up similar work, as some of the best known of the Cincinnati tool-building firms were established during the few years after Mr. Lodge's start.

In 1886 Mr. Barker sold his interest to Charles Davis. Lodge and Davis continued in partnership until 1892, when Mr. Lodge Lodge severed his connection with the firm and it later became the American Tool Works. They were employing at that time between 300 and 400 men. In March 1892 he organized the Ohio Machine Tool Company, and in August of the same year, became associated with Murray Shipley, forming the present Lodge and Shipley Machine Tool Company.

While the firm was Lodge and Davis, it built lathes, planers and drill presses. Mr. Lodge wanted to manufacture rather than build, and to specialize upon lathes. Mr. Davis, who was a business man, wanted a complete line of tools, as he saw the opportunity of selling other machines with the lathes. This led to the policy of concentrating upon the manufacture of engine lathes, and placing orders for other types of tools with mechanics just starting up, or with workmen from their own plant whom they helped to start in business.

Mr. Lodge had, during his apprenticeship in the shops of Fairbairn and Company, where specialization of manufacture was carried out to a marked degree, completely absorbed the idea of the manufacture of machinery in large lots. He was particularly well known for the fact that he was one of the first, if not the first, to specialize in the manufacture of one type of machine tool only, instead of making a few of many kinds of machine tools.

Some of the firms whose principals were in one way or another associated with Mr. Lodge were the Fosdick Machine Tool Company, Boye and Emmes Machine Tool Company, Dreses, Mueller and Company and the Cincinnati Planer Company.

Mr. Lodge was a member of the Engineers' Club of Cincinnati, the Machinery Club of New York, the Ohio Manufacturers' Association and various other organizations; and was especially active in

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the National Metal Trades Association, of which he was treasurer for three years. He was one of the organizers of the National Machine Tool Builders' Association and served as its president for two years.

He became a member of the Society in 1890. He died on April 30, 1917.

LUIS G. MARQUINA

Luis G. Marquina was born in 1871 in Lima, Peru. He was educated in the Colegio de Guadalupe, Lima, and received his engineering degree in 1893 from the Escuela de Ingenieros, Lima.

His practical experience in general engineering was gained in the Casapalca and Rayo Smelting Works and with the firm of Backus and Johnston. From 1893 to 1897 he was in the drafting room of the Peruvian Corporation, Ltd., at Lobos Island. From 1897 to 1902 he was with the same company as superintendent and engineer of the Pascamayo Railroad. For the next four years he was general superintendent and engineer of the Eten Railroad. About 1907 he returned to the Peruvian Corporation and at the time of his death was general superintendent and engineer of that company.

Mr. Marquina became a member of the Society in 1906. He died on June 18, 1917.

EDWARD J. MARTIN

Edward J. Martin was born on September 7, 1882, in West Roxbury, Mass. He was educated in the public schools of Boston, and later served an apprenticeship as machinist. He was a graduate of the mechanical-engineering course of the International Correspondence Schools, and also of the Emerson Institute of Efficiency. At the time of his death he was secretary and manager of the Connecticut Electric Manufacturing Company.

He became a member of the Society in 1915. He died on April 7, 1917.

WILLIAM F. MATTES

William F. Mattes was born on September 29, 1849, in Scranton, Pa. When seventeen years of age he was made superintendent of a small mining railroad near Mount Hope, N. J., and he continued in the iron-mining industry in New Jersey and later in Virginia, until 1882, when he was made chief engineer of the Lackawanna Iron and

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Steel Works, of Scranton. In 1888 he became general manager of the West Superior Iron and Steel Works, West Superior, Wis. He was director of the First National Bank, president of the Manufacturers, Shippers and Jobbers Association, and park commissioner of that city.

In 1893 failing health compelled him to move to Colorado, where he was interested in mining enterprises for several years. Later he returned to Scranton and was made chief engineer of the Lackawanna and Wyoming Valley Railroad Company while the Laurel line was in the process of construction. When his brother, Charles C. Mattes, died, he succeeded him as general manager of the Lackawanna Iron and Coal Company.

He was a member of the American Institute of Mining Engineers, The Franklin Institute, and the New York chapter of the Sons of the Revolution. He became a life member of the Society in 1882. He died on February 3, 1917.

GUY EDWARD MITCHELL

Guy E. Mitchell was born on March 4, 1869, in Lowell, Mass. He attended the public schools of that city and later entered the Massachusetts Institute of Technology, from which he was graduated as a mechanical engineer in 1891.

He was employed for a number of years by the Boston and Maine Railroad and worked up from the position of chief draftsman to that of consulting engineer of that company. After leaving the Boston and Maine Railroad he was located in New York for about three years as consulting engineer. He then served in various important capacities in the building of the Berkshire trolley system. Upon the completion of that work he became associated with the Alden Sampson Company, Pittsfield, Mass., builders of large automobile trucks, and acted as general manager for a period of seven years. Later he assisted in the building of the Hampden Railroad.

In December 1914 he was appointed manager of the municipal gas and electric light plant, Westfield, Mass. He held this position at the time of his death.

He became a member of the Society in 1903. He died on October 18, 1917.

JOSEPH MORGAN

Joseph Morgan was born on July 27, 1842, in Philadelphia. He was educated in the Central High School of that city, devoting

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himself to the sciences. In the fourth year of his course he entered the steam-engineering corps of the United States Navy. In 1861 he entered active service as third assistant engineer and was promoted to the rank of second assistant engineer in 1863. In 1866 he resigned and entered the service of the Phoenix Iron Company, Phoenixville, Pa., as draftsman. In 1868 he had risen to be chief draftsman, when he resigned to take a similar position with the Edge Moor Iron Company. About 1879 Mr. Morgan became associated with the Cambria Iron Company, Johnstown, Pa., as draftsman. He was made chief engineer in 1881, and after twenty-five years' service in that capacity was relieved of his more active duties and made consulting engineer of the Cambria Steel Company.

Mr. Morgan designed and superintended the various parts of the works of that firm, including six blast furnaces, new bessemer works of the largest class, new blooming mill, open-hearth plant, rail mills and various large mills of the Gautier plant involving the expenditure of millions of dollars. He was the consulting engineer in charge of the building of the Quemahoning Dam in 1913, and later of the Saltlick Dam.

In 1884 Mr. Morgan went abroad to make a study of gun and armor forgings. He visited the principal cities of England and the Continent where armor-making works were located. Later he was appointed a member of the United States Fortification Board, and wrote several valuable papers to aid in instructing the public on the subject, as well as for the information of Congress. He was familiar with the art of steel making from the date of the inception of the bessemer process up to the present time.

Mr. Morgan was a member of the United States Naval Institute and the Grand Army of the Republic and also held many offices in fraternal organizations. He was vice-president of the Society from 1886 to 1888 and chairman of the Sub-Committee on Iron and Steel for the year 1913–1914. He became a life member of the Society in 1881. He died on December 9, 1917.

LUCIUS LAWRENCE MOSES

Lucius L. Moses was born on November 26, 1868, in Marcellus, N. Y. He was educated in St. John's Military School, Manlius, N. Y., and later took a special shop course in Cornell University.

From 1889 to 1893 he served his apprenticeship with the Phoenix Foundry and Machine Company, Syracuse, N. Y. He then entered

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the employ of the Paragon Plaster Company, as construction and operating superintendent, having complete charge of the engineering work and of the manufacturing. His next position was with the Clyde Gas and Electric Company, Clyde, N. Y., as treasurer and general manager. Mr. Moses held chief engineer's papers for ocean-going vessels, and from 1901 to 1909 he was in the service of the United States Government in that capacity. In 1909 he became associated with Henshaw, Bulkley and Company, San Francisco, Cal., as construction engineer, and later became consulting engineer in charge of the engineering work of the Hallidie Machinery Company, Seattle and Spokane, Wash. At the time of his death he was practising as a consulting engineer in Seattle.

Mr. Moses was a member of the Marine Engineers' Association, Seattle and San Francisco. He became a member of the Society in 1912. He died on October 15, 1917.

CHARLES E. NEWTON

Charles E. Newton was born in Hartford, Conn., in 1858. He was educated in the public schools of that city, leaving the high school to enter the employ of the Jewell Belting Company in Hartford as office boy, where his ability speedily won him promotion. He became salesman for the company and was on the road for a number of years, winning more than usual success in this capacity.

In 1892 Mr. Newton was elected secretary of the company and later became assistant manager. His responsibilities were increased gradually, and in August 1917 he became president of the company.

Mr. Newton was elected to membership in the Society in 1895. He died on November 15, 1917.

ALFRED J. ORMSTON, JR.

Alfred J. Ormston, Jr., was born in Oil City, Pa., on July 6, 1883. He received his early education in the parochial and public schools and the private school of Dr. Samuel Earp, of Oil City.

For several years thereafter he was employed in the office of Alfred Smedley, chief engineer of the National Transit Company, in Oil City, in the capacity of clerk and stenographer, resigning to engage in business for himself in the production of oil.

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He later entered Carnegie Institute of Technology, Pittsburgh, and was graduated in 1912, having completed the course in mechanical engineering. After serving for a year as instructor in the Institute he was employed by the Massey Machine Company, of Watertown, N. Y., in the capacity of mechanical engineer. While with this firm he invented and took out letters patent on a small governor for engines. He assigned this patent to the Massey Machine Company, who manufactured it as their "Type O."

From Watertown Mr. Ormston moved to Woodlawn, Pa., where he was employed by the Jones and Laughlin Steel Company. For a time he occupied the position of assistant master mechanic, and at the time of his death was assistant to Mr. C. L. Dudley, steam engineer.

Mr. Ormston became a member of the Society in 1913. He died on July 31, 1917.

OSCAR PATRIC OSTERGREN

Oscar Patric Ostergren was born in Sweden in May 1866. He was educated in Stockholm, graduating from the Royal Technical High School with the degree of M.E. in 1888. From 1888 to 1891 he was employed by Treacher, Tenac and Company, civil engineers and contractors, in drafting and surveying a new railroad at Rosario, Argentina. The next year he spent with the Atlas Machine Company, Stockholm, as assistant engineer. He came to New York late in 1892, and was employed in erecting machinery by Robert Hoe and Company. From 1893 to 1896 he worked with Charles D. Mosher, a naval architect of New York, in designing marine engines, and until 1898 he was with Charles L. Seabury and Company, New York City, in the same line of work. He then became president and general manager of the Ostergren Manufacturing Company, having complete charge of the inventing and designing of liquid-air machinery, internal-combustion engines and automobiles. From 1902 to 1904 he was with the Fuel Oil Power Company as an inventor and designer of fuel-oil engines. Later he held successively positions with Benjamin Hurd, New York City; Joseph Boyer, Detroit, Mich.; Alger Brothers Detroit, Mich; and with the Grenetso Engineering Company. He held fifty United States patents on inventions.

Mr. Ostergren became a member of the Society in 1910. He died May 11, 1917.

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DWIGHT BOYCE PANGBURN

Dwight B. Pangburn was born in Washington, D. C., on Nov. 27, 1889. Later the family moved to New Haven, Conn., where he was educated in the public schools, being graduated from the high school in 1907. The same year he entered Yale University in the Sheffield Scientific School, where he took the regular course in mechanical engineering and was graduated in the class of 1910. He continued his studies in the same line until 1912, when he received the degree of mechanical engineer. He was then appointed an instructor in the mechanical-engineering department in Sheffield and held that position at the time of his death.

Mr. Pangburn's shop experience was limited. However, during one summer vacation he acted as consulting engineer for the Hendee Manufacturing Company, and during the following college year he conducted some scientific tests of the Indian motorcycle for the company at Mason Laboratory, Sheffield.

He wrote many scientific articles for various publications, and also a number of short stories for popular magazines. He was a recognized authority on bird life and was a charter member of the New Haven Bird Club. At the time of his death he was collaborating with Prof. Richard S. Kirby in writing a textbook on descriptive geometry.

Mr. Pangburn became a member of the Society in 1912. He was also a member of the National Geographic Society. He died on August 24, 1917.

CHARLES D. PARKER

Charles D. Parker was born in 1858 in Worcester, Mass. He was educated in the public schools of that city and later attended Worcester Polytechnic Institute, being graduated with the class of 1879.

His first position was with the Crompton Loom Works at Worcester, where he worked at pattern-making for about six months. For the next year and a half he was in the drafting room, and at that time took charge of the pattern-making and drafting departments. For the last fifteen years of his life he was mechanical expert of the A. Burlingame Company, Worcester, Mass., builders of steam engines and sawmill outfits.

Mr. Parker became a member of the Society in 1886. He died on December 7, 1917.

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JAMES JOHNSON PEARD

James J. Peard was born in New York City on July 25, 1849, and was educated in the public schools of Hartford, Conn. After leaving school he entered the employ of Colt's Patent Fire Arms Manufacturing Company, in whose shops he learned his trade.

In 1873 he went to Providence where he worked with the Providence Tool Company, and afterward with the Brown and Sharpe Manufacturing Company. In 1876 he became a contractor in the employ of the Remington Arms Company, Ilion, N. Y., and after remaining there five years returned to the Colt company at Hartford. In the employ of this concern he gradually worked up until he became assistant superintendent in 1888 and superintendent in 1902. He retained the latter position until 1911, when he retired because of ill health.

For twelve years Mr. Peard was a member of the Board of Education of Hartford, serving as its secretary and president. He was a member of the Colt Mutual Benefit Association, which he organized and served as president until 1914. He was the inventor of many improvements in the products of the Colt establishment and was a recognized authority on firearms.

He became a member of the Society in 1891. He died on July 3, 1917.

WALTER BEVERLY PEARSON

Walter B. Pearson was born in Madison, Wis., on Dec. 2, 1861. He spent his boyhood in Wisconsin and obtained his education there, completing it with two years spent in the University of Wisconsin, where he specialized in mechanics. Upon leaving the University he went to Cleveland, where he took a position with the Warner and Swasey Company.

He left this firm to become assistant superintendent of the Prospect Machine and Engine Company, Cleveland, resigning in June 1887 to take a position as salesman with the Cummer Engine Company in Chicago. Later he worked in the same capacity for Ide and Company, and for the Ball Engine Company, both of Chicago.

In the meantime he organized the Pearson Machine Company, manufacturing special machinery of his own invention and later specializing in producing and selling machine-screw products manufactured on the Pearson automatic screw machines.

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In 1900 the Pearson Machine Company was acquired by the Standard Screw Company, and in 1901 Mr. Pearson became a director and vice-president of the latter company. In 1904 he was elected president. Under his able management the company grew in strength and importance, absorbing in the meantime a number of the smaller machine-screw companies.

Mr. Pearson was a member of many clubs and societies, including the Engineers' Club of New York and the Chicago Engineers' Club.

He became a member of the Society in 1886. He died in Chicago on May 19, 1917.

LEWIS R. POMEROY

Lewis R. Pomeroy was born in Port Byron, N. Y., in February 1857, and was graduated from the Irving Institute, Tarrytown, N. Y. He early entered the railroad field, where his work attracted considerable attention. From 1886 to 1890 he was a special representative of the Carnegie Steel Company, introducing basic boiler steel for locomotives and special forgings for railways. For nine years he was engaged in similar work with the Cambria Steel Company and the Latrobe Steel Company jointly. He then became connected with the Schenectady Locomotive Works as assistant to the general manager, a position he held until 1902.

During the following six years he was a special representative for the General Electric Company in the railway field, this work covering the electrification of steam roads and railway shops and general application of electricity to all railway purposes. Subsequently, for two years, he was assistant to the president of the Safety Car Heating and Lighting Company, leaving to become chief engineer of the railway and industrial division of J. G. White and Company. Late in 1911 he resigned to open an office in New York City as a consulting engineer. In 1914 he became associated with the U. S. Light and Heat Company as manager of its New York office. About a year or so prior to his decease he again engaged in consulting work along lines in which he was qualified by his wide experience.

Mr. Pomeroy was a member of the American Institute of Electrical Engineers, the American Master Mechanics' Association, the Railroad Club of New York, the Engineers' Club of New York, and the New York Railroad Club. He joined the Society in 1890 and was chairman of its membership committee at the time of his death, which occurred on May 7, 1917.

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JOSEPH REID

Joseph Reid was born on November 11, 1843, in Maybole, Ayrshire, Scotland, where he attended the public schools until his eleventh year. He then was apprenticed by his father to learn the joiner's trade, at which he worked for four years. Later he became a machinist in the railroad shops of the Glasgow and Southwestern Railroad Company, Kilmarnock, Scotland.

In 1863 Mr. Reid located in Montreal, Canada, where he worked for a short time as machinist, after which he followed his trade in the United States, and was for some years connected with the Baldwin Locomotive Works in Philadelphia. In 1876 he entered the service of the Atlantic and Great Western Railroad Company, now the Erie Railroad, at Meadville, Pa.

In the following year Mr. Reid went to Oil City, where he worked with W. J. Innis and Company, and also with the firm of Malcomson and Patterson. When the latter firm failed in business, he bought their shop and started a small business of his own. In addition to general jobbing work, he made a specialty of refinery supplies. The opening of the Lima, Ohio, oil fields found the refiners unable to take care of the grade of oil produced in that field. The oil, however, could be used as fuel, and after careful experiment Mr. Reid designed, patented and manufactured a line of oil burners which were very successful and to handle which in 1885 he formed the Reid Burner Company.

As the result of extensive experiment, Mr. Reid brought out in 1894 what is believed to have been the first practical natural-gas engine, and by 1899 had made many improvements in it. The small repair shop became a large factory and the Joseph Reid Gas Engine Company was organized with Mr. Reid as president. He assisted also in organizing the Frick-Reid Supply Company, a large oil concern in the West, and was vice-president and director of this company. He was also president of the Reid Land and Development Company, which operated fruit ranches in the West.

Mr. Reid became a member of the Society in 1904. He died on October 23, 1917.

JOHN RIDDELL

John Riddell was born in Ireland in 1852 and was conspicuously a self-made man. At the age of about thirteen years, in Jersey City, he started as an apprentice in the jobbing machine shop of Nicholas

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B. Cushing, who made elevators and repaired machinery, especially marine engines. This work brought him in contact with marine circles, which resulted in his later serving two years as second engineer on trading steamers plying between New York and Caribbean ports.

His first association with the electrical business was with the Daft Electrical Company, where he did considerable experimental mechanical work in the railway field. In 1887 he entered the employ of the Thomson-Houston Electric Company at Lynn, Mass. In 1888 he became foreman of the railway motor shop and was recognized as one of the leading mechanical experts at the time the General Electric Company was formed in 1892.

Mr. Riddell moved to Schenectady in 1895, and shortly after his arrival was appointed mechanical superintendent of the company. In this important position he designed and had built special machine tools for increasing the production of the machine shops and also for carrying on the many special processes involved in the manufacture of mechanical tools. He was consulted in regard to all automatic machinery and his resourceful genius was called in when a solution was sought for different mechanical problems of a baffling nature. The records of the United States Patent Office show that 37 patents were taken out in his name.

In the sense that Mr. Riddell could obtain large outputs from machine shops with a minimum cost, he might well be termed a manufacturing economist. He was responsible for the location of machines and machine tools and his advice and opinion were sought in regard to such manufacturing problems as the routing of the materials from the time the raw materials were received until the finished product was ready for shipment.

Among the notable achievements of Mr. Riddell in the various works of the General Electric Company was a boring mill — the largest in the world when made — which was built from his design and which had a 60-ft. swing. This was so successful for machining the large wheels for the rotors and stators of water-wheel-driven generators that he designed a 40-ft. boring mill embodying the same principles as the large one, which was used for turbine work.

Another one of his designs was a bucket-cutting machine for large steam turbines which he developed in 1902. It was at this time that the General Electric Company was building the first 5000-kw. steam turbine ever constructed, and this labor- and time-saving device became an important factor in the development of the steam-turbine

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industry at the time when the steam engine was preëminent in the largest power plants in the world.

Almost automatic was the field-coil-winding machine which he built and which was adopted both in Lynn and Schenectady. It was a labor saver and a time saver, and in the opinion of many persons there was no single achievement of Mr. Riddell's which advanced the electrical industry more than did this winding machine.

Mr. Riddell was a member of the Engineers' Club of New York and the Society of Engineers of Eastern New York. He became a member of the Society in 1895. During his later years he delivered several papers on engineering subjects before various associations. He was awarded a gold medal at the Panama-Pacific International Exposition at San Francisco in 1915, as collaborator in the exhibit of the General Electric Company at the Exposition. He died in Schenectady, N. Y., December 31, 1917.

GEORGE SMITH RIDER

George S. Rider was born in Providence, R. I., on May 4, 1858. Upon leaving college he served an apprenticeship with the Brown and Sharpe Manufacturing Company in Providence, and then spent a number of years in their shops. Later he traveled abroad extensively, and upon his return he became connected with the Warner and Swasey Company at the time of the construction of the Lick telescope.

Mr. Rider's next position was with the Cummer Engine Company, from which he resigned to become an instructor in drawing and machine work in the University School of Cleveland, where he remained for about twelve years.

During these years at the University School Mr. Rider also carried on a private business as a consulting engineer, which in later years developed into the firm of George S. Rider and Company, consulting and designing engineers, of Cleveland, Ohio. He was the senior member of this firm up to the time of his death — a period of about fifteen years, during which he designed many large and important power and industrial plants in that part of the country.

He was a member of The Franklin Institute of Philadelphia, the Cleveland Engineering Society, and the Cleveland Chamber of Commerce.

Mr. Rider became a member of the Society in 1900. He died on September 11, 1917.

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MYRON KNOX RODGERS

Myron K. Rodgers was born in Pennsylvania in November 1861. He was graduated from Washington and Jefferson College in 1886, taking the first prize in chemistry.

He left immediately for the West, obtaining a position as rodman on the Montana Central Railroad, then building into Butte. He was rapidly promoted until he was made resident engineer, having charge of several tunnels. When this road was completed he obtained a position as surveyor with the Anaconda Copper Mining Company, and was advanced in a short while to the position of chief engineer, which he held until 1896.

At that time he became associated with Mr. Marcus Daly, of New York, becoming his mining expert and traveling all over the world examining mining properties for him. In 1907, acting for himself, he opened up the Nickel Plate Mine at Hedley, in British Columbia, and also the Hidden Creek Mine of the Granby Company, taking both of these properties as mere prospects and developing them until they were ready for the reduction works. He designed and built the Hedley Gold Mining Company's mill. In 1912 he became interested in mining properties in Mexico, which could not, however, be operated on account of the revolution.

Mr. Rodgers became a member of the Society in 1894. He died in June 1917.

SYDNEY FRANCIS SAVAGE

Sydney F. Savage was born in 1889 in Cambridge, Mass., and received his early education in that city. He was later graduated from Lowell Institute.

He was employed in an engineering capacity with manufacturing concerns in the vicinity of Boston, including the Blake-Knowles Steam Pump Works and the Hood Rubber Company, until 1914, when he entered the employ of the United Illuminating Company, New Haven, Conn., in the engineering department.

Upon the formation of the firm of Westcott and Mapes, New Haven, he joined the organization as mechanical engineer, later becoming director and assistant secretary and successfully directing many important undertakings.

He became a junior member of the Society in 1914. He died on August 18, 1917.

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GEORGE E. SCARFE

George E. Scarfe was born in London, England, in November 1886. He received his education in the London grammar schools, and when still very young started to learn his trade by becoming a machinist's helper.

His bent was toward electrical science, and in 1890 he accepted a position as engineer with an electric lighting company in New York. He resigned in 1892 to become associated with the Western Electric Company, in whose employ he was sent to San Miguel, San Salvador, Central America, as assistant engineer of construction on an electric-light plant there. Subsequently Mr. Scarfe held the positions of chief engineer of the Towanda Electric Lighting Company, and construction engineer of the Warren Manufacturing Company, Sandusky, Ohio.

In 1900 he became associated with the Pacific Gas and Electric Company in its Nevada division in charge of the power plant, and in 1904 became manager of the South Yuba Water Company. Mr. Scarfe's ability was evidenced not only in the immediate work of the company, but as a consulting engineer for the large gold-mining companies of that region.

After several years' connection with the Pacific Gas and Electric Co., Mr. Scarfe was appointed to the office of district superintendent, which position he held till April 1916, resigning to enter the private practice of electric and mechanical engineering, when he acted as consulting engineer for the Pacific Gas and Electric Company, Empire Mines Company, Pittsburgh Mines, South Eureka Mines, and a number of others.

Mr. Scarfe was an associate member of the American Institute of Electrical Engineers. He became a member of the Society in 1916. He died at his home in Nevada City on August 24, 1917.

HENRY SOUTHER

Major Henry Souther was born at Boston in 1865 and was graduated in 1887 from the Massachusetts Institute of Technology, where he specialized in mining and metallurgical subjects. After studying abroad the manufacturing methods and processes employed in the German iron and steel industry, he entered in 1888 the employ of the Pennsylvania Steel Company, at Steelton, Pa., and was made assistant foreman the following year. He was engineer of tests for the

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company from 1890 to 1893, resigning to become engineer of tests for the Pope Manufacturing Company, a position which he held for six years. At the Pope works he organized what was probably the first testing plant ever installed by a consumer of steel for the scientific testing of materials, and developed the use of cold-drawn tubing for bicycles and automobiles.

When the Pope organization was dissolved in 1899 Major Souther engaged in business as an independent consulting engineer and established a metallurgical and testing laboratory and did consulting work for the automobile industry. He was president and treasurer of the Henry Souther Engineering Corporation, of Hartford, Conn., from 1899 to 1909 and became president in 1911, but in later years was not very active in the management of that organization. He was vice-president and general manager of the Ferro Machine and Foundry Company, Cleveland, from 1915 until the United States entered the war. Later he had charge of the aircraft development of the army and created a corps for the inspection of aircraft. At the time of his death he was senior officer of the Aircraft Engineering Division, Aviation Section, Signal Corps, U. S. A., and vice-president of the company bearing his name.

Major Souther was prominent in the Association of Licensed Automobile Manufacturers, was a founder member of what later became the Society of Automotive Engineers, and had much to do with the development of the iron and steel standards of that body. He was president of that society in 1911 and served as chairman of the standards committee for a number of years. In 1915 he was made a life member in recognition of this work.

He became a member of the Society in 1894. He died August 15, 1917, at Fortress Monroe, Va.

ALBERT C. STEBBINS

Albert C. Stebbins was born on September 19, 1845, in Monson, Mass., and received his education in the Monson Academy. When nineteen years old he came to New York City and worked for William Soules in the wool and flax business. Feeling the necessity of taking up a trade, he apprenticed himself as machinist with Lucius W. Pond, Worcester, Mass., from 1865 to 1870. In 1870 he went to New York as representative of Mr. Pond. Five years later, when the business changed hands and Mr. Pond's son, David W. Pond, took charge, Mr. Stebbins went back to Worcester as superintendent. In 1886,

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when the Pond Machine Tool Company was established, Mr. Stebbins was made vice-president and went to Plainfield, N. J., where he built the plant and had it running in the spring of 1888. In 1898, on the formation of the Niles-Bement-Pond Company, Mr. Stebbins was made vice-president and manager of the Pond works and continued in this capacity until the time of his death. He was also vice-president of the Pratt and Whitney Company, director of the Ridgway Machine Company and vice-president of the Plainfield Savings Bank. He became a member of the Society in 1904. He died in Plainfield, N. J., February 28, 1917.

JOSEPH STEHLIN

Joseph Stehlin, who was born in New York City in 1875, received his early education in the public schools and later attended the Stevens Preparatory School and the Stevens Institute of Technology, graduating from the latter in 1898 with the degree of M.E.

Directly upon leaving school, Mr. Stehlin entered the drawing-room of P. Pryibil and soon after that of C. W. Hunt and Company. His shop experience was obtained while with J. Ruppert and as assistant engineer with the Nestlé Food Company, 1899. In 1900 he became associated with the New York Central Railroad as assistant mechanical engineer, and in 1903 became mechanical engineer, superintending erection of power stations, cooling plants, water stations, lighting, and power and steam equipment of yards and buildings. He severed this connection in 1906 and founded the Stehlin-Miller-Henes Company, steam and electrical engineers and contractors. In 1908 he became also associated with the Farmers' Feed Company, of which his father was president, and in 1909 upon the death of his father, he succeeded to the presidency of the company.

Mr. Stehlin was elected to membership in the Society in 1905. He died on January 22, 1917.

HENRY G. STOTT

Henry Gordon Stott was a native of the Orkney Islands, Scotland, where he was born in 1866. After a thorough grounding in the fundamentals at the hands of his father and elementary school instructors, he was enrolled as a student at the Watson Collegiate School, Edinburgh. On leaving this institution he entered the College of Arts and Sciences at Glasgow, and began a course in mechanical engineer-

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ing and electricity, graduating in 1885. In the year previous he had entered the employ of the Electric Illuminating Company of Glasgow. Shortly after graduating he was made assistant electrician on board the steamship *Minia*, belonging to the Anglo-American Telegraph Company. For the next four and a half years he was engaged with those duties, during the course of which he saw much service in connection with repairs to the cable lines of that company. In this period he undertook a number of experiments that resulted in the introduction of improved methods of handling cable repairs. He was also identified with the "duplexing" of the United States Cable Company's main cable (2750 knots), the longest duplex cable in the world.

In 1889 Mr. Stott was made assistant engineer of the Brush Electric Engineering Company's plant at Bournemouth, England. The following year he was offered a post by Hammond and Company as assistant engineer in the construction of an underground cable and power plant at Madrid, Spain. He remained there until 1891, when he came to the United States to install an underground cable and conduit system for the Buffalo Light and Power Company (now the Buffalo General Electric Company). This work was completed with a degree of success that reflected very greatly to the credit of Mr. Stott, and as a result he was named engineer of the company, and during the next ten years was one of the most active figures in the industrial progress of Buffalo. During this period he designed and executed some notable construction work, including a power plant on Wilkeson Street, Buffalo.

His work attracted wide attention and in 1901 he was appointed superintendent of motive power of the Interborough Rapid Transit Company, New York City, a position which he filled with signal success. At the time he took up these duties the Interborough had not yet been organized, the company having the title of the Manhattan Railway Company. The post which Mr. Stott was called to had just been created, and it devolved upon him to organize the operating force, in connection with which he completed the Seventy-fourth Street power plant of the company, various sub-stations and transmission lines.

When the Manhattan system was amalgamated with the Interborough, in 1904, Mr. Stott was invited to retain his office with the new corporation. He accepted and immediately took over supervision of the construction of the power plant on Fifty-ninth Street. From that time on he was constantly in charge of design, construc-

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tion and operation of the power-generating stations and the distributing system of the Interborough, which included the subway, elevated and surface lines of New York City. The plans for the electric-power system of the later subway lines were also developed under his supervision.

Mr. Stott was a firm believer in coöperation among engineers through the agency of the engineering societies. He was elected president of the American Institute of Electrical Engineers for the term of 1907–1908, in which society he was a member of the Standards Committees, the Public Policy Committee, the Committee on Development of Water Power, the United States National Committee of the International Electrotechnical Commission, the Power Stations Committee, the Committee on Economics of Electric Service, and the Edison Medal Committee. He was also one of the Institute representatives on the Joint Committee on the Metric System, of which he was an ardent advocate. He was a director of the American Society of Civil Engineers in 1911.

Mr. Stott became a member of the Society in 1902, was a manager from 1907 to 1910 and from 1911 to 1912, and vice-president from 1912 to 1914. He served on the Special Committee on Pipe Thread Gages in 1913 and 1914, as chairman of the Committee on Flanges and Pipe Fittings from 1912 to 1914, as chairman of the Conference Committee on Electrical Engineering Standards in 1913 and 1914. He was a member of the Executive Committee of the Council in 1913 and 1914, a member of the Advisory Committee of the Boiler Code Committee, and in 1916 was appointed a member of the Standardization Committee. He represented the Society on the Board of Trustees of the United Engineering Society, of which latter he was vice-president at the time of his death.

As a result of his unusually wide experience and extended research, Mr. Stott was called upon often to contribute papers to the various engineering societies. He was especially well known for his minute analysis of engineering problems. Among the large number of papers which he wrote were those on The Conversion and Distribution of Received Currents; Power Plant Economics; Notes on the Cost of Power; Steam Pipe Covering and Its Relation to Station Economy; Tests of a 15,000 Kilowatt Steam Engine Turbine Unit; Power Plant Design and Operation (a series), etc.

Mr. Stott was a remarkable figure in the engineering world because he was in the front rank of both electrical and mechanical engineers; because in both branches of the art he was a master of

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theory and practice, and because with these technical qualifications he combined a rare executive ability and power of inspiring the confidence of his employees and of bringing out the best that was in the men who worked for him.

He died at his home in New Rochelle, N. Y., on January 15, 1917.

FRANK L. STRONG

Frank L. Strong, who was born in Amherst, Mass., in 1845, was educated in the public schools of Andover, Mass., and later in Phillips Academy. After leaving school he decided to become a machinist and accordingly apprenticed himself to the Davis and Furber Machine Shop, at North Andover Depot, where he remained two years. When the Civil War broke out, he enlisted and worked his way up to the rank of third assistant engineer in the Navy, receiving his honorable discharge at its close. He returned to Chicago in 1867 and finally settled there, having been in charge of various large manufacturing plants before he became superintendent and part owner of the Hercules Refrigerating and Ice Machinery Company.

In June 1898, at the outbreak of the Spanish-American War, he again enlisted as engineer, this time becoming chief engineer of the Illinois Naval Reserves. He returned to Chicago in 1899, entering the field of consulting mechanical engineering, and in 1900 was retained by the Quartermaster-General of the Army as consulting engineer and superintendent of erection of the refrigerating and ice-making plant at Manila. In 1902, when this work was completed, he opened an office for himself under the name of the Frank L. Strong Machinery Company and engaged in private practice, also representing a number of home manufacturers.

Mr. Strong was a member of the Business Men's Association in Manila, a member of the Loyal Legion, the Sons of the American Revolution and a number of local clubs in Manila. He was a prominent worker in the Masonic Order, and was Master of the first lodge in Manila. He became a member of the Society in 1912. He died on January 12, 1917.

GERALD EDGAR TERWILLIGER

Gerald E. Terwilliger was born on January 9, 1888, in Newark, N. J. He received his early education in the Barringer School,

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Newark, and entered Stevens Institute of Technology in 1905, from which he was graduated in 1909.

For the next two years he studied law and in 1911 was admitted to the bar of New York State. He specialized in patent law, where his technical training made him very successful. In addition to his legal profession, Mr. Terwilliger was interested in literary work, writing for newspaper and magazine publications. He was the editor of the *Stevens Indicator*, an alumni publication of Stevens Institute.

He became a member of the Society in 1910. He died on December 9, 1917.

SVERRE TRUMPY

Sverre Trumpy was born in Bergen, Norway, in January 1882. He was educated in a German preparatory school and received the degree of B.M.E. in 1903 from the Royal Technical University, Berlin.

During his college course, from 1899 to 1903, he served his apprenticeship with the Accumulatoren Fabrik Aktiengesellschaft, Hagen, Westphalia. Upon graduation he accepted the position of assistant superintendent of the municipal electric plant, Bergen, Norway. His next position was with the Fort Wayne Electric Works of the General Electric Company, Madison, Wis., as machinist. In 1904 he became associated with the Gisholt Machine Company in Madison as draftsman, and in 1906 was made chief draftsman of the vertical-boring-mill department. In 1911 he was placed in charge of the engineering department and the drafting room.

Mr. Trumpy became a member of the Society in 1913. He died at his home in Madison, October 17, 1917.

EDWIN D. TUCKER

Edwin D. Tucker was born in New York City on October 10, 1865. He was educated in the public schools of the city and in Wilson and Kellogg's private school.

Upon leaving school he served his apprenticeship with the firm of R. Hoe and Company, and also obtained his drafting-room and shop experience with the same firm. He was later promoted to the position of foreman, holding this until 1906.

In the same year Mr. Tucker became associated with Sheppard Knapp and Company and was treasurer of the firm for five years, when he retired from active business.

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Mr. Tucker was a member of the General Society of Mechanics and Tradesmen, and of the Franklin Institute of Philadelphia. He was elected to membership in the Society in 1898. He died on July 9, 1917.

HAROLD VAN DU ZEE

Harold Van Du Zee was born in West Newton, Mass., on April 4, 1859. He attended the public schools of that city and later entered the engineering department of the Massachusetts Institute of Technology. He spent one year in miscellaneous drafting work for Frederick Tudor and Company and for the Hinkley Locomotive Works, both of Boston, Mass. For two years he was associated with Col. George E. Waring of Newport, R. I., as draftsman and was his assistant on sewage and drainage work in Memphis, Tenn., where he remained for about a year. The second year of this work he had charge of the sewage disposal of the Bryn Mawr Hotel. His next position was with the Tide Water Oil Company, Bayonne, N. J. At the time of his death he was in private practice in Philadelphia as a civil and sanitary consulting engineer.

Mr. Van Du Zee did much to beautify the suburban homes of Philadelphia, working in this connection with the Olmstead Bros., of Brookline, Mass. He also collaborated with the late Frederick W. Taylor in the scientific development of sod for golf grounds.

He became a member of the Society in 1885. He died on May 7, 1917.

CASIMIR VON PHILP

Casimir von Philp was born in Stockholm, Sweden, in 1853. After having finished his preliminary education he entered the Stockholm Institute of Technology and in due time was graduated therefrom.

His first position was in the office of W. Wennstrom, in Oerebro, Sweden, but he did not remain there long, and after holding several other positions finally engaged in consulting engineering work. He saw, however, that the United States offered a much broader opportunity, and in 1880 came here with his family.

Shortly after his arrival in America he obtained a position with E. D. Leavitt, of Boston, Mass., and while in his employ had complete charge of several important undertakings, among them being the sewage-pumping installation in Boston and the large pumping machinery constructed for the Calumet mines.

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After several years in Mr. Leavitt's employ, Mr. von Philp obtained the position of chief engineer with the Burden Iron Company, of Troy, N. Y. In 1890 he became the chief engineer of the Bethlehem Steel Company.

After sixteen years Mr. von Philp severed his connection with the Bethlehem Steel Company in order to devote all his efforts to his inventions in the field of presses. In 1908, however, he returned to the Bethlehem concern as manager of the machine department, a post which he occupied up to the time of his death.

Mr. von Philp was a member of the American Society of Swedish Engineers, American Society of Engineers, and of The Committee of Fifty, organized to erect a memorial to John Ericsson in Washington, D. C. He became a member of the Society in 1890. He died on July 4, 1917.

THOMAS C. WALKER

Thomas C. Walker was born in England in 1859. He was educated in the public schools there, and it was there also that he served his apprenticeship in machine work and tool making. He gained his shop experience with the Birmingham Small Arms Company.

For four years he was in charge of the machinery for the Carbon Mill in Colorado. He was also associated for about four years with the Denver and Rio Grande Railroad Company. At the time of his death he was president of the Walker Manufacturing Company, Denver, Col.

He became a member of the Society in 1891. He died on February 13, 1917.

WILLIAM FORGUE WAY

William F. Way was born on October 3, 1888, in Johnstown, N. Y. He was graduated from Rensselaer Polytechnic Institute in June 1913 with the degree of mechanical engineer. His shop experience was obtained in Hutton's Machine Shop, Seattle, Wash. Later he became associated with the Talbot Boiler Company, Seattle, as draftsman. He became a member of the Society in 1916. He died on December 18, 1916.

SILAS E. WEIR

Silas E. Weir was born on May 16, 1869, in Cookstown, County Tyrone, Ireland. He was educated at the Guilds Schools in London

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and served his apprenticeship with Coombe, Barboure and Coombe, Belfast, Ireland. Following this training, he went to British India to take charge of the installation and operation of a tea-drying plant located northwest of Calcutta. He had to give up this position, however, owing to illness, and he returned to Ireland for a period of about five years. He then came to the United States and worked for several firms — as general master mechanic with the Griffin Wheel Company, general superintendent with the Triumph Electric Company and works manager with the American Blower Company, retaining the last position until the time of his death.

Mr. Weir became a member of the Society in 1914. He died in Detroit on February 13, 1917.

DANIEL A. WIGHTMAN

Daniel A. Wightman was born in East Greenwich, R. I., on August 7, 1846. After having received his education in the schools of that place he learned the carpenter's trade, at which he worked while taking up the study of drawing at an evening school in Providence, R. I.

About 1870 he accepted a position as draftsman with the Rhode Island Locomotive Works, where he soon became chief draftsman and for a time virtually superintendent of the shops. In 1876 he was made superintendent of the Pittsburgh Locomotive Works and was with that concern until he retired in 1902, then holding the position of general manager. While at Pittsburgh Mr. Wightman rebuilt the plant and made many improvements in locomotive design, the most important of which was the introduction of power flanging in place of the hand method for heavy boiler sheets. After retiring in 1902 he did some consulting work for the Baltimore and Ohio and Lehigh Valley railroads in connection with locomotive repair shops.

He was a member of the American Railway Master Mechanics' Association. He became a member of the Society in 1884. He died in Warren, R. I., on July 6, 1917.

OTTO CHARLES WOLF

Otto Charles Wolf was born in Philadelphia, Pa., in 1856. His early education having been obtained in the public schools of Philadelphia, he took up the study of mechanical engineering at the University of Pennsylvania, from which he was graduated with honors in 1876.

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In furtherance of his profession he first entered United States Government employ as engineer and draftsman in the Ordnance Department, and was then set to making drawings of foreign army and navy equipment on exhibition at the Centennial Exhibition. Next, to acquire mechanical skill, he served an apprenticeship in a shop making a specialty of mint machinery, then with manufacturers of Corliss engines, power and machinery equipments, following which he served for three years with the Fred W. Wolf Company, of Chicago, as supervising engineer in the construction of enterprises requiring power plants and those in which artificial refrigeration largely entered.

In 1883 Mr. Wolf returned to Philadelphia and established himself as a consulting engineer and later as engineer and architect in the planning and erection of breweries, grain elevators, refrigerating plants, electric-lighting plants, and manufacturing industries requiring steam and electrical power and refrigeration. He was also frequently called on to make insurance and valuation surveys.

Among his many achievements was the planning of the shipyards of the Chesapeake Dry Dock and Construction Company at Newport News, together with its 700 residences and homes; also the Philadelphia Warehousing and Cold Storage Company, Northwestern National Bank, Northwestern Market Company, Consolidated and Consumers ice-manufacturing plants, and many bridge constructions, hotels, stores and residences.

At the time of his death Mr. Wolf was president of the Philadelphia Yeast Manufacturing Company, vice-president of the Northwestern National Bank, trustee and active supervisor at the German Hospital, trustee of the Atlanta Telephone Company, a member of the Association of Refrigerating Engineers, the American Institute of Architects, and The Franklin Institute. He was also a member of the mechanical section of the advisory committee of the University of Pennsylvania. Mr. Wolf became a member of our Society in 1889. He died at his home in Overbrook on December 19, 1916.

JOHN MITCHELL YOUNG

John Mitchell Young was born in Ardrossan, Ayrshire, Scotland, September 18, 1883. He received his early education in the Glasgow High School for Boys. He then entered the Glasgow and West of Scotland Technical College as a day student, graduating in 1904 from the mechanical-engineering course and being elected an associate of

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the college. During his last year in college he carried on investigations having to do with steam turbines, and for a thesis embodying these investigations he received the Montgomerie-Neilson gold medal and prize.

He then entered upon an apprenticeship in the works of William Young and Sons, engineers and ironfounders in Ardrossan. On the completion of his apprenticeship he became a draftsman of sugar machinery with Mirlees Watson and Co., Glasgow. In 1909 he came to the United States, where he took a position as draftsman in the steam-turbine department of the Fore River Shipbuilding Company, Quincy, Mass. He next turned his attention to electrical engineering, and took a position with the General Electric Company, Schenectady, N. Y., as draftsman. Later he took charge of the construction office for the power plant of the Toronto Power Company, Niagara Falls, Ont. He next took up the study of sugar machinery, and became a designer with the Dyer Company, Cleveland, Ohio, and later with the Geo. L. Squier Company, Buffalo, N. Y. For the former company he designed and equipped a complete sugar factory in Louisiana. He became interested in conveying and elevating machinery, and for the next two years occupied the position of factory equipment engineer and designer with the Otis Elevator Company, Buffalo, N. Y.

He was an associate member of the Institute of Engineers and Shipbuilders in Scotland. He became a member of the Society in 1915. He died on March 14, 1917.

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2 Titles of papers, where placed after the name of the author, and appearing in their exact form, are in italics. Papers are indexed not under their titles but under their subject-matter.

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